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VESSEL POLLUTION STUDY SAN DIEGO BAY, CALIFORNIA

Federal Water Pollution Control Administration
San Francisco, California

June 1969

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CLEAN WATER

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC SOUTHWEST REGION

VESSEL POLLUTION STUDY SAN DIEGO BAY, CALIFORNIA

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VESSEL POLLUTION STUDY

San Diego Bay, California

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this document may be better
studied on microfiche.

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC SOUTHWEST REGION
San Francisco, California

JUNE 1969

I

AERIAL VIEW OF SAN DIEGO BAY

ABSTRACT

A two-year study in San Diego Bay reveals that vessel waste discharges produce undesirable water quality conditions in areas of concentrated vessel activity.

The study examined the effects of waste discharges representative of up to one-fourth of the U.S. Navy's entire active fleet, more than twenty-five hundred pleasure craft containing sanitary facilities, over a hundred ships of the West Coast commercial fishing fleet, and commercial freight vessels carrying in excess of a million tons of cargo to the Port of San Diego each year. Wastes discharged from these vessels were found to create conditions that are hazardous to health, aesthetically offensive and damaging to ecological balances in San Diego Bay.

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I. INTRODUCTION

Statement of Problem

The problem of wastes from ships, boats, and other floating vessels has been receiving increased attention as a part of nation-wide efforts to clean up polluted waterways. In the past, vessel wastes constituted a very minor portion of the total pollutional burden carried by the nation's waters except in areas of high concentrations of vessels. In the future, as local pollution control programs become more effective, this source will assume ever greater importance.

Until recently, the water quality impact of sewage from vessels has been difficult to assess because of the presence of more extreme pollution from other sources. As a result, reliable data related to vessel wastes are limited.

The waters of San Diego Bay are subject to minimal domestic waste pollution from sources other than vessels, a condition that simplifies identification of vessel wastes and their effects. This, coupled with the bay's position of importance in military and commercial maritime activity on the West Coast and as the center of increasing aquatic recreational demands, led to the selection of San Diego Bay as the site for exhaustive study of vessel wastes in a marine environment.

Study Objectives

The objective of the Vessel Pollution Study has been to provide answers to the following questions:

What are the magnitude, extent and kind of pollutional effects of the discharge of wastes from vessels into marine waters?

What pollution prevention, control and/or abatement measures are necessary to reduce or eliminate adverse effects of vessel wastes on marine waters?

Scope

The Federal Water Pollution Control Administration, Department of the Interior, established the San Diego Bay Vessel Pollution Study Project in July, 1966, for the purpose of achieving the foregoing study objectives. This report is the result of two years of intensive field and laboratory activity. The work has involved an array of scientific disciplines including microbiology, aquatic biology, chemistry, oceanography, sanitary engineering and related areas.

The investigation considered wastes from all types and sizes of watercraft and from shore sources. Existing water quality was characterized throughout the bay with special emphasis on vessel concentration areas. Estimates were made of future quality of bay water considering long range harbor improvement plans and water quality control objectives.

The information and recommendations contained herein are considered to have application to pollution control efforts in many other restricted marine waters having significant vessel activity.

Authority

The Federal Water Pollution Control Administration is the agency of the Federal Government having primary responsibility for implementation of a national policy for enhancement of the quality of the Nation's water resources through the control of pollution. This policy has been spelled out in a series of legislative acts over the past decade which are described as the Federal Water Pollution Control Act, as amended (33 U.S.C. 466a et seq.). Section 5 (b) of this Act authorizes the Secretary, "upon request of any State water pollution control agency . . . ," to "conduct investigations and research, and make surveys concerning any specific problem of water pollution . . . with a view of recommending a solution of such problem."

The San Diego Bay Vessel Pollution Study was established in response to Resolution 64-7, adopted February 27, 1964, by the San Diego Regional Water Pollution Control Board, and Resolution 64-6, adopted April 8, 1964, by the State of California Water Quality Control Board. These resolutions requested a study of "the actual and projected effects of raw waste discharges from ships and vessels upon harbors and coastal waters."

Added impetus was given to the San Diego Bay Vessel Pollution Study by Executive Order 11288 issued

by the President on July 2, 1966, and titled, "Prevention, Control, and Abatement of Water Pollution by Federal Activities." Section 8 of this Executive Order is titled "Study of water pollution from vessel operations." It calls for the Secretary of the Interior to "make a comprehensive study of the problem of water pollution within the United States caused by the operation of vessels, and to "develop such recommendations for corrective or preventive action as may be appropriate, including recommendations with respect to vessels operated by any department, agency, or establishment of the Federal Government."

Acknowledgment

The Federal Water Pollution Control Administration received the assistance and cooperation of many individuals and agencies in the conduct of this investigation. The several agencies which provided direct assistance are listed below:

U.S. DEPARTMENT OF THE ARMY, CORPS OF ENGINEERS
- Los Angeles District

U.S. DEPARTMENT OF TRANSPORTATION
- U.S. Coast Guard

U.S. DEPARTMENT OF THE NAVY
- Eleventh Naval District
  - Headquarters,
  - Southwest Division, Naval Facilities Engineering Command

U.S. DEPARTMENT OF THE NAVY *(continued)*
- Pacific Fleet
  - Cruiser Destroyer Force
  - Service Group One
  - Submarine Flotilla One
  - Amphibious Force
  - Air Forces

STATE OF CALIFORNIA
- State Water Resources Control Board
- San Diego Regional Water Quality Control Board
- Department of Fish and Game
- Department of Public Health
  - Bureau of Sanitary Engineering
  - Sanitation and Radiation Laboratory

COUNTY OF SAN DIEGO
- City-County Health Department

CITY OF SAN DIEGO
- Utilities Department

SAN DIEGO UNIFIED PORT DISTRICT
- Public Works Department

Particular appreciation is expressed to Mr. Dennis A. O'Leary, Executive Officer, San Diego Regional Water Quality Control Board, for his counsel and encouragement throughout the course of the study.

II. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

San Diego Bay is a crescent-shaped natural harbor, about 18 square miles in area, with a single outlet to the Pacific Ocean. It is subjected to intensive vessel use. It is home port for nearly one-fourth of the U.S. Navy's entire active fleet. There are more than 2500 pleasure boats containing sanitary facilities and there is a commercial fishing fleet exceeding 100 vessels. In addition, commercial shipping amounts to more than one million tons of cargo annually.

Pollution from such vessel usage has received increased attention in recent years, particularly where local water quality control programs have been effective in dealing with municipal and industrial wastes. This is the case in San Diego Bay where wastes from commercial, military and recreational vessels are believed to be one of the major remaining sources of water pollution.

The Federal Water Pollution Control Administration initiated the Vessel Pollution Study in San Diego Bay to assess the magnitude, extent and kind of pollutional effects of vessel wastes and to identify necessary pollution prevention, control and abatement measures to deal with adverse effects of vessel wastes in marine waters. The study took place during the two-year period from July, 1966 to July, 1968 and was performed in response to a request by the State of California.

A sampling and analysis program designed to characterize present water quality, bottom deposits and the plankton and bottom-dwelling organisms of the bay was carried out. Water analyses included measurement of temperature, salinity, transparency, dissolved oxygen, nutrients, and bacteriological densities. Field observations of grease, oil, garbage and sewage solids were also made.

Prior to 1963, wastes from the surrounding metropolitan area were discharged to San Diego Bay. All but a very few minor domestic waste discharges were terminated in August, 1963, and at the present time only a few industrial waste discharges remain. Bacterial contamination traced to a kelp processing industry, storm water influences and sludge deposits laid down prior to 1963 were investigated to permit separation of vessel waste effects from shoreside influences.

Regulations of the Port District, the Navy and Coast Guard and the State-Federal Water Quality Standards for the Bay prohibits disposal of garbage, sewage and other floatable or settleable material to the Bay. However, the direct discharge of untreated sewage and other wastes from vessels is a common practice. Vessel wastes that reach the Bay include sanitary sewage (usually weaker than typical domestic sewage) and floatable material such as oil, garbage and trash.

Watercraft berthing areas and afloat populations were identified by vessel category. Typically, about 70 military vessels with an afloat population of slightly more than 10,000 men were observed in the Bay although there are port and mooring facilities for over 200 military vessels with an estimated maximum afloat population of nearly 40,000 men.

Commercial shipping activities are confined to frequent cargo ship visits of short duration, intermittent occupation by a 90-boat tuna fishing fleet and up to 200 small commercial craft and 35 larger charter sport fishing boats. Recreational watercraft number up to 2500 vessels actually moored in the Bay. Sanitary wastes from commercial and recreational watercraft were found to have a relatively minor influence compared to military vessel sources.

Water quality in most parts of San Diego Bay is at acceptable levels in contrast to the polluted conditions that existed prior to diversion of the major waste sources in 1963. Temperature, salinity, transparency, nutrients and associated plankton populations are generally within the limits set forth by State-Federal Water Quality Standards. Water quality problems exist however, due in part to vessel wastes. These problems include excessive amounts of floating materials (oil, trash, garbage and sewage solids), excessive bacterial densities including the presence of pathogenic bacteria, organic sludge deposits which limited the diversity of bottom organisms to the more polution tolerant forms, and some areas of depressed dissolved oxygen concentrations. The area of San Diego Bay having the highest coliform bacteria density was the Naval Station; the levels in this area were more

than twice the water quality standard for coliform bacteria.

Dye tracer tests, mathematical simulation models and field observations, including "before and after" studies, were employed to isolate vessel wastes from shore influences. Direct tagging of vessel sewage discharges was carried out to characterize the waste plume from a single vessel moored in the Bay. This work showed that bacterial densities due to discharges from a 400-man vessel rapidly diminished with distance from the point of discharge.

Conclusions

The investigations described in this report have led to the following conclusions:

1. Areas of San Diego Bay having intensive vessel activity are adversely affected by waste from watercraft. The most serious adverse effects are reflected by total and fecal coliform densities and the presence of Salmonella organisms and floating sewage solids in and on bay waters. Salmonella bacteria can readily be isolated from the waters of San Diego Bay in areas of concentrated vessel activity. The presence of such pathogenic bacteria is a hazard to the health of persons coming in contact with these waters.

2. Floatable materials such as sewage solids, trash, garbage and oil discharged to San Diego Bay by ships create aesthetically offensive conditions. Most oil observed in San Diego Bay results from carelessness in fueling and fuel transfer operations onboard ships and between ship and shore. Pumping of bilges in violations of rules and regulations is also a probable source of oil in the bay. Carelessness of individuals of the waterborne population in San Diego Bay brings large amounts of floatable trash and garbage into the bay.

3. Bottom deposits of decomposed and actively decomposing sludge resulting in part from settleable vessel wastes may be found in areas of concentrated vessel activity in San Diego Bay. These deposits upset the normal ecology of the bay by diminishing the diversity of benthic biota.

4. Water quality standards for San Diego Bay adopted by the state of California and approved by the Secretary of the Interior are being violated due in part to the discharge of vessel wastes. The specific provisions of these standards that are not currently being met in areas of concentrated vessel activity are those relating to dissolved oxygen, floating materials, bottom deposits, and bacterial densities.

5. The water quality and surface and bottom conditions of San Diego Bay can be improved by adequately treating all sanitary wastes from watercraft; by minimizing the occurrence of oil spills; and by vigorously enforcing regulations relating to disposal of trash and garbage from watercraft.

6. Any increase in the number of ships in San Diego Bay will increase total and fecal coliform densities and floating fecal solids unless adequate water pollution control measures are instituted.

Recommendations

Based upon the findings and conclusions of this study:

1. It is recommended that the discharge of untreated sanitary wastes from watercraft to San Diego Bay be discontinued. While watercraft are within the bay, their sanitary wastes should be (a) adequately treated prior to discharge to bay waters, or (b) collected for transfer to and ultimate treatment in shore facilities or for disposal at sea.

This recommendation could be implemented by installing treatment facilities aboard vessels that will (a) remove or control the solids fractions of the waste and (b) adequately disinfect the waste so as to continually assure the inactivation of pathogenic bacteria.

A more desirable alternative to shipboard treatment of watercraft wastes is the transfer of all wastes to onshore sewerage facilities either directly or after collection in shipboard, waterborne, or submerged holding devices.

2. It is recommended that strict compliance with regulations be made mandatory of all supervisory military personnel responsible for fueling and fuel transfer operations. Adequate training of all operating personnel in the proper procedures, and the use of penalties for carelessness should be instituted to eliminate to the maximum feasible extent accidental oil spills that occur during fueling and transfer operations. This same approach should be applied

to the improper disposal of trash, garbage and other refuse from military sources.

Since 90 to 95 percent of all vessel activity in San Diego Bay is conducted by the U.S. Navy, most of the oil spills observed are attributable to Naval activity. Recognizing this fact, the Navy has assumed responsibility for and is the only agency performing (by contract with local enterprise) oil spill cleanup operations in San Diego Bay. Although the number and extent of the spills that do occur are small relative to experience in many other harbors, considerable improvement is possible.

It should be possible to reduce the number of oil spills significantly by making it mandatory that proper authorities be informed in detail of all spills, rejecting the notion that spills are unavoidable, and by taking appropriate action to prevent repetition. While this would be a worthwhile effort to secure immediate improvements, a better longer range solution, as described in recommendation number 3, should also be pursued.

3. It is recommended that a thorough study be undertaken of large vessel fueling systems with the objective of developing improved methods that would greatly reduce or eliminate the probability of fuel spills due to human error.

Most of the larger oil spills to San Diego Bay occur during vessel fueling operations. Such spills generally result from operator error. These fueling operations, which are little changed from those in use for many years, could be redesigned to reduce the present reliance on human operators. An in-depth operational analysis of fuel transfer systems now in use would demonstrate which steps in the process can and should be redesigned to provide better process control and thereby minimize the incidence of spillage.

4. It is recommended that the enforcement of existing statutes and ordinances prohibiting the spillage of oil and the improper disposal of trash to the bay be vigorously pursued as a coordinated effort at the Federal, State and local levels.

A large part, if not all, of floating litter observed in San Diego Bay is due to the negligent habits of individuals. It is common practice to throw any and all unwanted items over the side, both at sea and in port. This practice in San Diego Bay results in unsightly accumulations of floating materials in downwind pockets and entrapments in many locations in full view of harbor sightseers. Some accumulations or floating "rafts" of these wastes also become hazards to small boat navigation.

Authority to regulate the improper disposal of trash and garbage from watercraft in San Diego Bay is vested in a number of agencies at three levels of government; Federal, State and local. It seems probable that much of the litter found in the bay today could be eliminated by a vigorous and coordinated enforcement program involving all concerned agencies. Such a program should be accompanied by a continuing educational program. Posting of appropriate notices at all marinas and boat launching facilities and a number of well publicized arrests and convictions would increase the importance of this matter in the public consciousness and should contribute significantly to minimizing the volumes of floating matter now found in harbors.

III. DESCRIPTION OF STUDY AREA

Historical Development

San Diego Bay was discovered in the year 1542 by Juan Rodriquez Cabrillo. The bay was later named by the Spanish explorer, Don Sebastian Viscaino, in 1602, who described the harbor as "the best in the whole South Seas." It is still considered to be one of the ten best natural harbors in the world.

The first Spanish settlers arrived in the area in 1769 and established a small community at the mouth of the San Diego River. The bay was used extensively by American whalers during the eighteenth and nineteenth centuries. In 1846 the United States Navy sloop-of-war USS Cyane entered San Diego Bay under wartime orders, and a landing party together with land forces under John C. Fremont, raised the American flag over the presidio which overlooked the little town.

San Diego began to grow after moving to its present site in 1867, becoming a city in 1872 and a port of entry in 1874. The population stood at 30,000 in 1900 and had risen to about 200,000 by early 1940. With the advent of World War II the number of persons more than doubled in a very short time. During 1969, when the City of San Diego is celebrating its bicentennial, the estimated population for all the cities and towns contiguous to San Diego Bay passed the one million mark.

The use of San Diego Bay by the U. S. Navy dates back to 1842 with frequent visits by Navy ships recorded to the end of the century. However, no major naval activity took place until 1901 when the Navy acquired land for establishment of a coaling station on Point Loma. Growth was limited then until 1914 with emphasis mainly on naval communications and aviation. Between 1914 and 1923, several important installations around the bay were commissioned, including establishment of the Eleventh Naval District. Today, the Navy contributes over one billion dollars annually to the economy of San Diego. San Diego Bay is homeport for about one-fourth of the Navy's entire active fleet.

Development of San Diego Harbor into a commercial port got fully under way in about 1918, with progress to that time consisting of a few wharfs and piers and some minor dredging. Records of cargo tonnage handled by the port indicate an increase from about half a million tons annually to one and one-half to two million tons in recent years. Cargo value over the same period has increased from twenty million dollars in 1920 to more than 328 million in 1967. The seafood industry also grew with the port until in 1950 some 2,500 persons were employed in the fishing fleet and some 3,300 worked in the processing and canning factories. At the present time, improvements in fishing techniques and automation in the canneries have reduced these numbers considerably. Since 1962 control of the Port of San Diego, except for military installations, has been under a unified port authority.

The recreational boating fleet in San Diego Bay experienced only gradual growth until the end of World War II. San Diego Yacht Club, the first of its kind in San Diego, was established in 1886. With later establishment of other such clubs of boating enthusiasts, recreational boating in the bay consisted mainly of occasional sailing regattas between clubs. Increasing interest in aquatic recreation following World War II and completion of Shelter Island in 1951 with its yacht and commercial basins brought a rapid rise in the popularity of recreational boating. A 1956 inventory by the Port Authority of shallow draft boats based in San Diego Bay (boats large enough for sanitary facilities) showed a total of 1,442 (1). This number includes commercial sportfishing boats but does not include the several thousand trailered boats that use the many launching facilities located on San Diego Bay. The Port Authority's 1967 inventory of shallow draft boats showed a count of 2,500 (1).

Physical Description

San Diego Bay is situated in the extreme southwest corner of California, a few miles north of the International Boundary between the United States and Mexico. (See Figure 1.) It is a crescent-shaped

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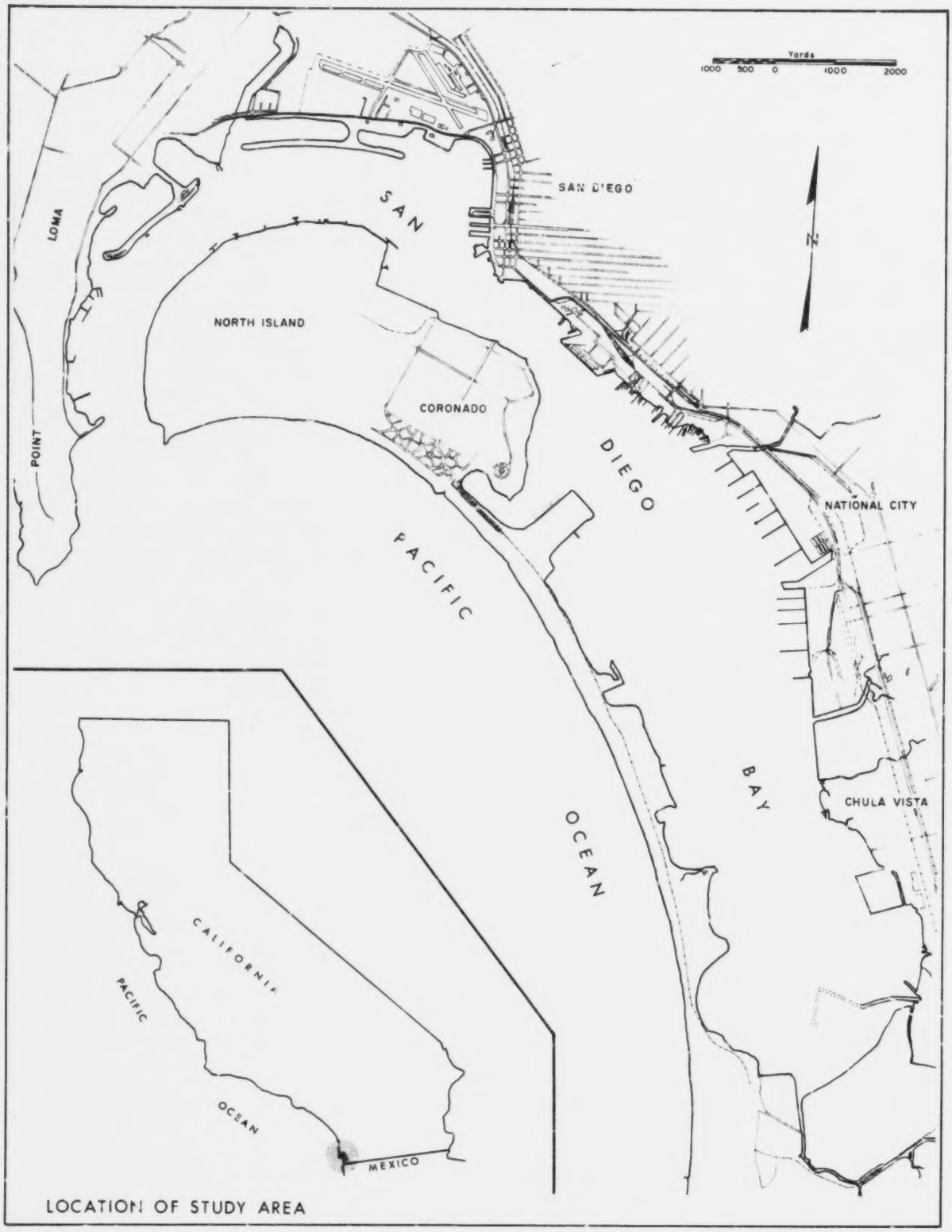
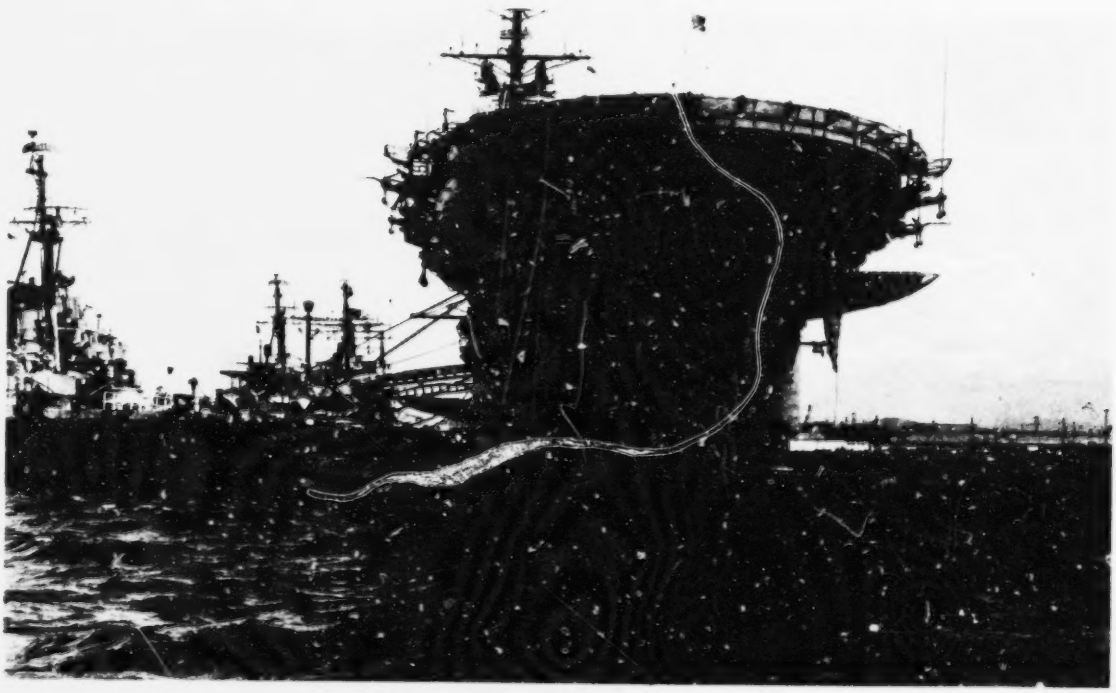


Figure 1. San Diego Bay

Naval Vessels in Naval Station Area



Aircraft Carrier Moored in Naval Station

body of water about fifteen miles in length, varying in width from one-quarter to two and one-quarter miles, with a surface area of about 18.5 square miles. Its depth varies from zero (mud flats exposed at low tide) at the southern end to over sixty feet near the harbor entrance. San Diego Bay has two ephemeral rivers, Sweetwater and Otay, and three or four so-called creeks tributary to it. Fresh water flows from these tributaries only after or during periods of prolonged or heavy rainfall. Such occurrences are infrequent and of short duration.

Climate

The climate of the area is described by the San Diego Chamber of Commerce as the finest in the United States. The mean annual temperature is 61.5°F. The average high temperatures in the coldest and warmest months differ only fourteen degrees. The area receives an annual average rainfall of ten inches from November through April and averages 353 days of sunshine each year. Gentle winds averaging eight to nine miles per hour complete the picture of near perfect climate in the San Diego Area.

Water Uses

The water uses of the bay have kept pace with history. In the early periods following discovery, deep water ships sought refuge for rest and repair on its tranquil waters just as they do today. Later on, during the calving seasons of the California Gray Whale, "shore whaling" was practiced in San Diego Bay. Harbor development and activity eventually drove the whales far south into Mexican waters. Still later, one portion of the bay was used as a mill pond to receive giant log rafts towed in from the Pacific Northwest. Throughout the history of San Diego Bay, its waters and tidal flats have been a nursery, feeding ground, and refuge for fish and wildlife. Finally, the bay has been used as the receptacle for most of the wastes from the communities developing on its shores since the first municipal sewer was constructed in 1887.

Deterioration of water quality as a result of waste discharges began to be a serious problem in mid 1930's. By 1942 a waste treatment plant for metropolitan San Diego had been completed. It was overloaded the next year and bay water quality continued to deteriorate. 1951 saw expansion of the treatment works but again overloading caused further degradation of water quality. By 1960 most of the bay had been quarantined and posted by health authorities to prohibit body contact uses. Continuous algal blooms reduced water clarity often to less than one foot and colored the water various shades of green, red and brown. Dissolved oxygen levels were depressed to the extent that bait and game fish virtually disappeared. Aquatic training by the military was seriously curtailed. Aesthetic uses were reduced. A sludge bed 200 yards wide, 9,000 yards long, and one to three feet thick, leading from the treatment plant outfall, was reported in 1951 (2). By 1963 its depth had increased to over seven feet.

After completion of the giant San Diego Metropolitan Sewerage System in August, 1963, which includes interceptors, pumping and treatment facilities with an ocean outfall, the discharge of virtually all municipal wastes and a large percentage of industrial wastes into San Diego Bay was eliminated. Water quality recovery was swift and spectacular. Algal blooms virtually disappeared and clarity increased markedly within weeks. Fish and wildlife soon began to return. The sludge bed began to reduce in size and depth and presently is confined to only a few isolated deposits.

The major categories of contemporary water usage of San Diego Bay include maritime, military, industrial, recreational, fish and wildlife and aesthetic uses. These beneficial water use categories and more specific deliniations of these uses are further described in the San Diego Regional Water Quality Control Board's Water Qaulity Control Policy for San Diego Bay. (3) This Policy has been approved by the State Water Resources Control Board and, with certain limited exceptions, has been found by the Secretary of Interior to be consistent with the Federal Water Pollution Control Act. This Policy, therefore, represents joint state-federal water quality standards for San Diego Bay.

IV. ORGANIZATION OF SAMPLING PROGRAMS

General

The sampling programs were designed to characterize the present water quality conditions in San Diego Bay, and to determine the influence of vessel wastes on this water quality.

Evaluation of existing water quality in the bay was necessary to locate and define areas of significant pollution. It also served to establish background levels of pollutants for comparison with levels found in areas of concentrated vessel activity. One hundred fifty-seven sampling stations were established employing a 2500-foot grid interval overall with a 1250-foot interval in areas of maximum vessel activity and water movement (Figure 2). The sampling methods used are described on Appendix A.

Random Sampling

For a given sampling run both station and depth for the sample were selected at random. Between October, 1966 and November, 1967, fifty-one random sampling runs were conducted. The frequency of sampling runs and the number of stations sample each run varied throughout this period. Table 1 gives the details of sample numbers and frequency.

Table 1

SUMMARY OF RANDOM SAMPLING PROGRAM

Dates	Average Sampling Interval	No. of Random Runs	No. of Sta. Visits/ Runs	Number of Sta. Visits
Oct. 4– Nov. 4, 1966	Daily	27	15	405
Nov. 9– Nov. 30, 1966	Weekly	4	20	80
Nov. 30, 1966– Nov. 20, 1967	Bi-weekly	20	20	400
			Total	885

Measurements were made of temperature, salinity, transparency, dissolved oxygen, principal nitrogen and phosphorus forms, and bacterial density. Observations of grease, oil, floating garbage and sewage solids were recorded.

As the study progressed some observations and analyses were eliminated where evaluation of the data indicated insignificant variation or concentration. Analytical methods used are described in Appendix B.

By sampling from the entire bay and from the full range of environmental conditions experienced, it was possible to obtain a good description of general water quality as well as a clear delineation of those sections most significantly influenced by pollutants. The effects of two previously undisclosed sources of bacterial contamination were revealed early in the random sampling program.

Intensive Sampling

The influence of vessel wastes on water quality was further defined by intensive bacteriological sampling in selected areas. This was accomplished through concentrated sampling in all moorage zones under specific sets of environmental conditions.

Many samples were also taken in the industrial zone in attempts to locate an unknown source of bacterial pollution. Table 2 summarizes the major non-random sampling efforts.

Table 2

SUMMARY OF CONCENTRATED SAMPLING PROGRAM

Location	Number of Sampling Runs	Total Number of Samples
Submarine Base	1	16
Mid-bay Area	5	99
Carrier Basin	3	140
Naval Station	4	160
Industrial Zone	5	224
Yacht Harbor – Commercial Basin	2	27

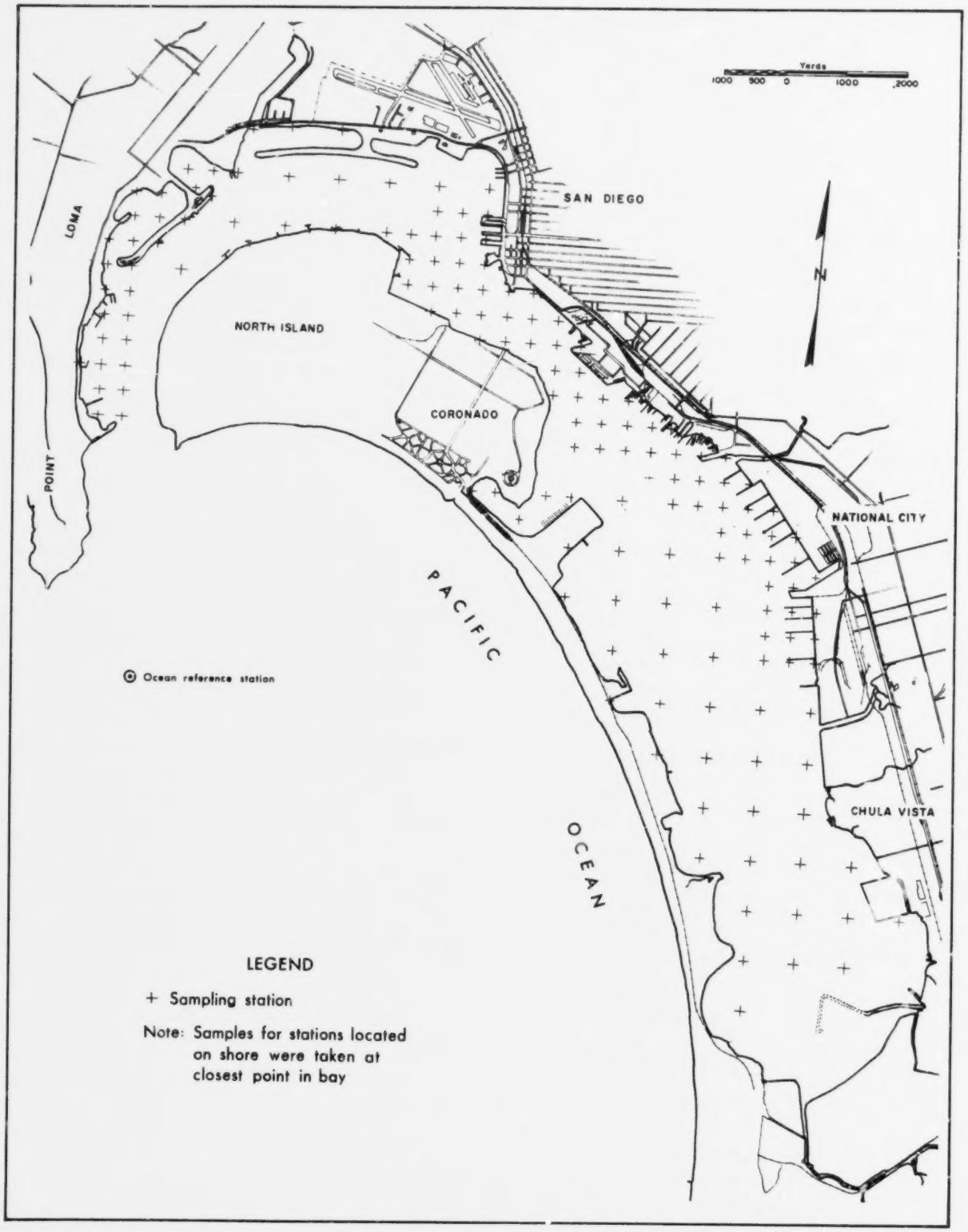
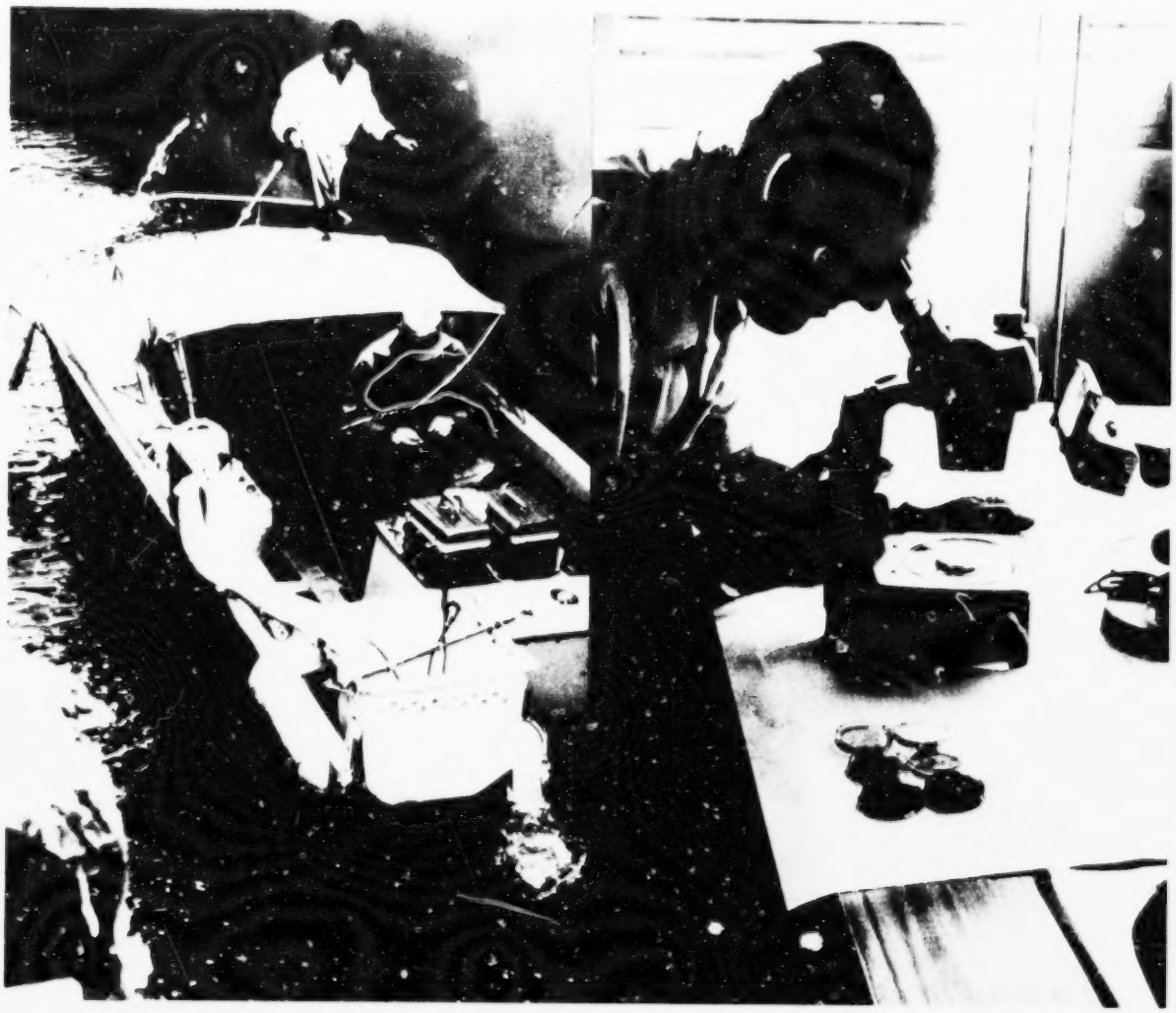


Figure 2. Sampling Station Grid

Benthic conditions were assessed using a Petersen dredge and a Phleger type coring device to obtain bottom samples and depth cores at fifty-nine sampling stations throughout the bay. Special emphasis was given to areas of more intense vessel activity and near the known sources of industrial discharges. For example, fifteen stations were established in the U. S. Naval Station, five in the adjacent industrial zone and five in the vicinity of the "B" Street storm (zoo) drain outfall. Three sampling stations were established each in the Carrier Basin, the Commercial Basin, within and adjacent to the Shelter Island Yacht Harbor, and in the Reserve Fleet anchorage. The remaining twenty-two stations were scattered throughout the bay.

Plankton samples were also collected and preserved from scattered points in the Bay during May, August, October and December 1967 to reflect seasonal changes. Phytoplankton were identified and enumerated.



Sampling Alongside a Destroyer

Microbiologist Examining Bacterial Colonies

V. WASTES FROM SHORE SOURCES

Municipal Wastes

The discharge practices for municipal wastes generated in the San Diego metropolitan area have changed drastically in recent years. Prior to 1963, the domestic wastes from the communities in the area were discharged to the bay in the amount of 55.6 million gallons/day (MGD). These wastes received at most primary treatment and chlorination, and were discharged through five separate outfalls. Three of these outfalls were located on the east side of the bay in National City and Chula Vista, and two served the Coronado Naval Amphibious Base complex. The adverse effects of these discharges on water quality in the bay were evident. Dissolved oxygen was low, coliform levels high, and extensive sludge deposits accumulated (2, 4).

These discharges were terminated in August, 1963, when the San Diego Metropolitan Sewerage System went into operation. All municipal wastes receive primary treatment at the Point Loma Sewage Treatment Plant and are disposed of through a deep ocean outfall. Only a few minor shore sources of sanitary sewage continue to discharge into the bay.

Industrial Wastes

At the beginning of the study, industrial wastes from fourteen sources were being discharged into the bay. Table 3 lists the more important ones together with their pertinent characteristics. During the course of the study, many of the industrial discharges were either eliminated or reduced in strength as a result of cooperative action between industry and the San Diego Regional Water Quality Control Board.

Figure 3 indicates the locations of the various discharges. The numbers refer to those in Table 3.

Early in the study a discharge from shore was discovered which has not been included in Table 3. Unaccountably high total and fecal coliform concentrations in water samples obtained near "B" Street Pier led to an investigation which revealed that flow-through and wash-down waters from a section of San Diego Zoo flow into storm drains which enter San Diego Bay under the "B" street Pier. Water flowing from duck, seal and hippopotamus ponds and wash-down water from bird cages and various animal grottos is retained in a lined tank at a low point on zoo property, then periodically sluiced out into the city storm drainage system. This procedure causes the volume and characteristics of the flow to vary considerably but the overall effect on the bay water and bottom sediments in the vicinity of the discharge is quite significant (5, 6). The City of San Diego is now working with the zoo management to divert these wastes to sanitary sewers.

By early December, 1966, results from the initial water quality sampling program indicated a distribution of coliform organisms which seemd to be anomalous to the known sources of bacterial pollution. Coliform concentrations found in an industrial waterfront area were two to three times greater than those found in an adjacent area of intense vessel activity. This anomaly led to several investigations among which were: concentrated bacteriological testing throughout both areas; bacteriological die-off and regrowth studies; sampling and testing of all accessible industrial discharges; sampling and testing of storm drains suspected of carrying wastes other than storm water; determination of water movement between the areas using dye tracers; sanitary surveys of industrial and public utilities by City of San Diego personnel; and finally, visual search of suspect areas by divers equipped with SCUBA.

These investigations revealed that coliform concentrations generated in adjacent vessel activity areas were insufficient to produce the higher concentrations found in the industrial area. Further investigation revealed these high bacterial densities were due to a previously unsuspected waste stream from a kelp processing firm. Extremely high bacterial densities were found in this waste stream (see Table 3) and apparently originate in kelp washing and holding tanks before any of the material enters in-plant processing.

Stormwater

San Diego is located in an extremely water-short area requiring therefore that most normal surface flows of fresh water be impounded for water supply purposes. As a result, there is practically no natural surface runoff into the bay. However, runoff does

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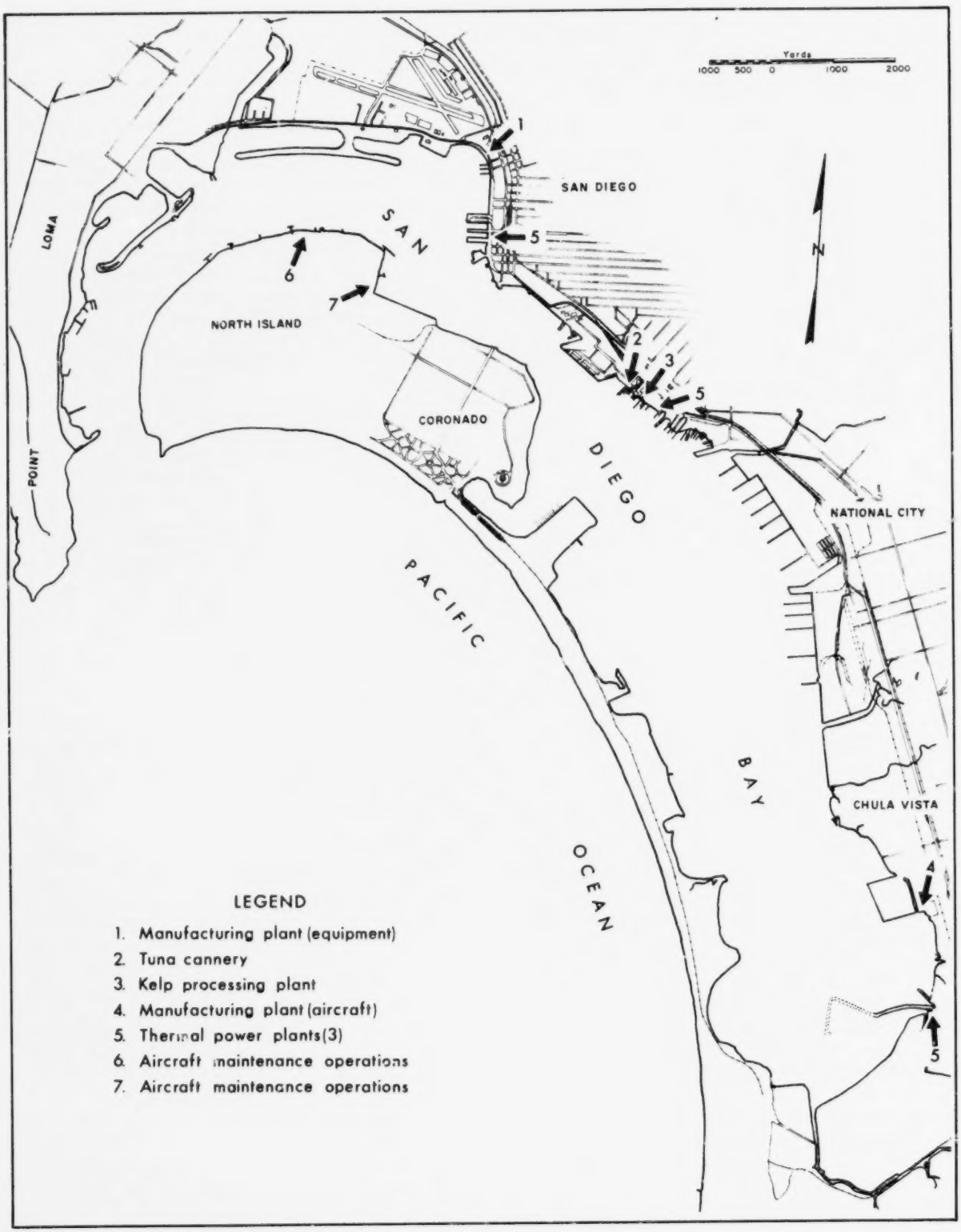

Figure 3. Major Industrial Waste Sources

Table 3

CHARACTERISTICS AND POLLUTION LOAD OF MAJOR INDUSTRIAL WASTE DISCHARGES*

Source	Nature of Discharge	Characteristics		Loading
1. Solar Corp., manufacturing plant	Metal treatment process rinse water	Volume, mgd	0.086	
		Total heavy metals, mg/1	44	32 lbs/day
		Oil-grease, mg/1	51	36 lbs/day
2. Westgate-Calif. Corp. tuna cannery	Fluming and thawing water	Volume, mgd	1	
		BOD, 5-day-20°C, mg/1	320	2,670 lbs/day
		Suspended solids, mg/1	157	1,310 lbs/day
		Phosphates, mg/1	8	67 lbs/day
		Nitrates, mg/1	34	284 lbs/day
3. Kelco Co., kelp processing plant	Kelp pulp, process chemicals, filter aid	Volume, mgd	1.62	
		BOD, 5-day-20°C, mg/1	2500	33,700 lbs/day
		Suspended solids, mg/1	3750	50,600 lbs/day
		Phosphates, mg/1	37	500 lbs/day
		Nitrates, mg/1	75	1,010 lbs/day
		Total coliform bacteria,** median, MPN/100 ml	36×10^6	2.2×10^{15} organisms/day
4. Rohr Corp., manufacturing plant	Metal treatment process rinse water	Volume, mgd	0.3	
		Total heavy metals, mg/1	100	250 lbs/day
5. San Diego Gas and Electric; thermal power plants (3)	Cooling water	Volume, mgd (total)	375	
		Average temperature increase of 11-12°C above ambient		
6. U. S. Navy, aircraft maintenance & repair operations	Paint stripping and aircraft wash water	Volume, mgd	0.143	
		Solvents, detergents, paint stripping debris		
***7. U. S. Navy, aircraft maintenance and repair operations	Metal treatment process water and industrial washwater	Volume, mgd	0.086	
		Phenols, mg/1	150	108 lbs/day
		Grease and oil, mg/1	260	186 lbs/day
		Chromium, mg/1	0.1	0.07 lbs/day

*Data provided by State of California, San Diego Regional Water Quality Control Board.

**Additional data given in Appendix B.

***Values are approximate only.

NOTE: It is reported (13) that most of the suspended solids from Kelco eventually settle to the bay floor.

occur during and immediately after a heavy or prolonged rainstorm, entering the bay through five or six natural water-courses and a large number of storm drains.

The water quality in the bay near these discharges is seriously impaired as a result of storm runoff. Turbidity is very high as is the coliform bacterial count. The City of San Diego reports that sanitary sewers in older sections of the city tend to surcharge and overflow during rainstorms. This runoff contributes to the observed water quality impairment. Dairy farming operations located near the ephemeral streams discharging to San Diego Bay may also contribute to the impairment.

Interfering Effects

The contamination of San Diego Bay by some of the shore sources tends to interfere with evaluation of the effects of vessel wastes. Effluent from the kelp processing plant of the Kelco Company is of primary concern in this regard. This waste has high biochemical oxygen demand (BOD) and solids concentrations and very high levels of coliform bacteria. The high levels of contaminants and the proximity of the discharge point to the major vessel berthing areas makes difficult a precise evaluation of the bacteriological and oxygen consuming effects of vessel wastes.

Analysis of benthic conditions is complicated by the presence of sludge deposits left from previous municipal discharges and from continuing discharges in the industrial waterfront. The San Diego Municipal outfall was located at the end of Pier 5 in the Naval Station and extensive sludge deposits accumulated both within the anchorage and downbay. In the Carrier Basin, sludge deposits were built up primarily from the sewer outfall of the City of Coronado. Although the extent and depth of the sludge has decreased since 1963, deposits remain. The decomposition of these deposits tends to mask the adverse effects of sediments from vessel wastes.

Total Pollution Load

Total pollution loads in pounds per day in the major industrial discharges to San Diego Bay are shown in Table 3.

The Kelco Company discharge by itself contains BOD and suspended solids equivalent to approximately 200,000 and 250,000 persons, respectively, and on this basis is greater than all other waste discharges into San Diego Bay combined.

VI. WASTES FROM WATERCRAFT

Location of Anchorage Areas

The watercraft berthing areas in San Diego Bay are located in the lower two-thirds of the bay. Within this area there are nine major moorages; four used by military vessels, three by commercial watercraft and two basins for recreational watercraft. Figure 4 indicates the location and type of watercraft using these areas.

Afloat Populations

Military vessels represent the greatest afloat population on San Diego Bay. The U. S. Naval Station has the largest population, followed by the North Island Carrier Basin. Table 4 summarizes the afloat population data for the military anchorages and indicates the wide fluctuations possible during the weekdays. On weekends, the situation changes. There are larger numbers of ships present but because of the absence of personnel on weekend liberty, the net result is a lower population. In the Naval Station, for example, the number of ships averages ten to twenty percent higher than on weekdays. The afloat population, however, averages about seventy percent of weekday figures.

Population estimates for commercial shipping activities are based upon the number of full ship-days/day (in port) allowing for the fact that most commercial freighters are in port for only a few hours. The major area of commercial shipping activity is the Tenth Avenue Marine Terminal. The average number of ship-days/day for this area is slightly over one, representing a population equivalent of forty-five to fifty men. The estimated maximum is about 225.

The other commercial shipping area is located near the "B" Street Pier. This includes "B" Street Pier, Broadway Pier, Navy Pier, and some smaller commercial piers. The average number of ship-days/day for this area is 0.30, which represents about fifteen man-days. Once or twice a year, one of the piers is used as an embarkation point for troops deploying overseas. For a period of a few hours, the population may reach several thousand. Excluding these conditions, an estimated maximum is 100-125 man-days.

Approximately ninety large tuna fishing boats operate out of San Diego Bay with an average crew of twelve men/boat. Under usual operating conditions no more than twenty-five percent are in port

Table 4

SHIP NUMBERS AND POPULATION DATA FOR MILITARY ANCHORAGES IN SAN DIEGO BAY[1]

Location	Average Day		Maximum Day		Minimum Day		Peak Month-Average Day		Maximum Possible	
	No. of Ships	Population[2]	No. of Ships	Population	No. of Ships	Population	No. of Ships	Population	No. of Ships	Population
U. S. Naval Station	52	7,040	66	10,000	46	3,610	54	7,940	120	18,000+
North Island Carrier Basin	2+	1,780	5	4,850	0	0	2+	2,470	5+	6,700
Submarine Base[3]	10+	1,010	12	1,400	1	428	12+	1,250	24	2,800
Mooring Buoys[4]	5	820	13	2,542	0	0	8+	1,340	58	11,000
Totals	69+	10,650	96	18,792	47	4,038	76+	13,000	207	38,500

1. Values are for weekdays only. (The data were collected over a twelve-month period from August, 1966 to August, 1967. Estimates are based on an average of seventeen days of ship count per month.)
2. Population figures are expressed in terms of man days (i.e., total man-hours of occupancy divided by 24).
3. Data for Submarine Base are for period August, 1966 to March, 1967.
4. All berths and mooring buoys occupied by single ship.

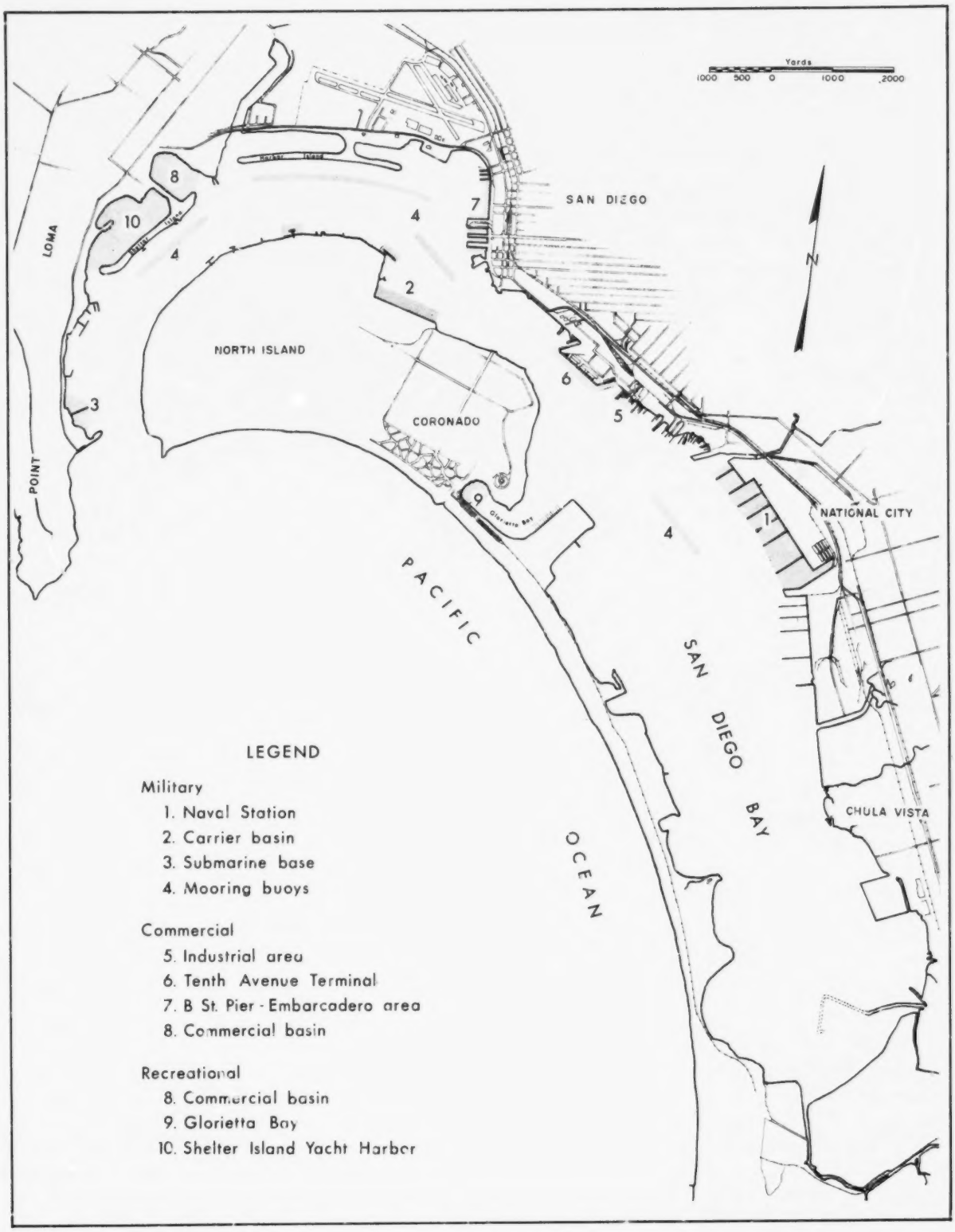

Figure 4. Vessel Berthing Sites

at any one time. Most of these would be using the net mending facilities along the Embarcadero north of "B" Street Pier. The work done here is carried out for the most part on shore and only two or three men are left on board. Fifty to sixty boats would be the maximum for this area representing a peak population of 150 to 200 man-days.

Two other commercial fishing activities based in the bay are located in the Commercial Basin at Shelter Island. These involve about 200 small to medium sized boats and thirty to thirty-five large charter and open-party sport fishing boats. The fishing boats are used only during certain seasons and no information is available as to percentage of use, number of crew members, etc. The sport fishing boats operate on a regular basis throughout the year and are at sea at least half the time. The man-day population represented by the open-party and charter boats is in the range of twenty-five to fifty. During the hour or two preceding departure, however, the customer population on these boats might reach or exceed 500-600.

The afloat population attributable to recreational boating is the most difficult to assess. There are between 2,000 and 2,500 recreational watercraft moored in San Diego Bay. Approximately 1,600 are in the Shelter Island Municipal Yacht Harbor. The percentage actually in use as reported by marina operators varies from less than five percent on a weekday to twenty to thirty percent during a maximum use weekend such as Labor Day or the Fourth of July. Predominant use of these boats, however, is in the ocean rather than the bay. An estimate of the maximum recreational boating population in the bay is eighty to ninety man-days/day.

Waste Disposal Practices

Disposal practices vary according to the type of waste and type of watercraft. In all types of watercraft using San Diego Bay, sanitary and other wastes are discharged directly overboard. In the case of recreational watercraft, however, this is generally true only while the boats are underway outside the harbor and marina areas. Disposal of sewage, trash and garbage within the Bay is also prohibited by section 8.50 of the Unified Port District Code. Enforcement of this regulation is delegated to the Harbor Police who report very few violations. Port District, Coast Guard, and Navy regulations also prohibit the disposal of garbage and trash into the waters of San Diego Bay. Some spillage occurs, however, in the process of transferring garbage and trash from ship to lighter and lighter to shore. Careless and negligent habits of individuals in disposal of personal litter and garbage also contribute significantly to the volume of these materials observed in the bay.

Discharge of petroleum products and bilge water is expressly forbidden by State, local and/or Navy regulations. "Accidents" however do happen and oily materials are frequently observed in San Diego Bay. Negligence and improper practices during fueling and fuel transfer operations are the predominate cause of oil on San Diego Bay.

Sanitary Waste Characteristics

Sampling was carried out on three U. S. Navy ships to evaluate the characteristics of the Sanitary wastes being discharged. The effluents sampled were from typical head compartments and contained wastes from toilets, urinals, showers, washbasins, and general purpose sinks. Table 5 summarizes the results obtained.

Table 5

AVERAGE ANALYSES OF SANITARY SEWAGE FROM NAVAL VESSELS

Per capita flow, gpd	37.7
Total coliform bacteria 100 ml, arithmetic avg.	1.3×10^6
Fecal coliform bacteria 100 ml, arithmetic avg.	5.8×10^5
Biochemical Oxygen Demand, 5 day 20°C, mg/1	86
Settleable solids, mg/1	68
Nitrogen, ammonia, mg/1 as N	7.0
Nitrogen, nitrate, mg/1 as N	0.38
Nitrogen, nitrite, mg/1 as N	0.02
Nitrogen, Kjeldahl, mg/1 as N	52.7
Ortho-phosphate, mg/1 as PO_4	10.8
Total phosphate, mg/1 as PO_4	17.4

These results are in reasonable agreement with those obtained in vessel waste characterization studies carried out by the U. S. Navy Marine Engineering Laboratory (7, 8), which report a lesser average per capita flow and somewhat higher coliform, BOD and nitrogen averages, probably because only toilet and urinal wastes were included in the effluents tested.

Oil and Perlite Offshore from Industrial Waterfront

Oil Slick in Naval Station

Samples for waste characterization were taken outside the ships from overboard discharge points. These points were no more than 30 feet from source facilities and as a result fecal solids were not broken up to the extent found in a typical domestic sewage. This, coupled with the fact that the vast majority of visible solids discharged settled rapidly out of sight within a few feet of the discharge point, made fully representative samples difficult to obtain with the equipment employed.

Solids analyses were further complicated by the high background dissolved solids in the salt water flushing systems common to all seagoing vessels. The increment of solids added by the wastes is very small by comparison making accuracy of the determinations questionable. However total, total dissolved, suspended (by difference), total volatile, total volatile suspended, and one hour settleable solids were measured. Because of the unstable platform on the work boat the settleable solids determinations were made in tall, approximately 2 gallon, containers on shore. The composite was vigorously mixed therein and a one liter sample taken. The remainder was allowed to settle for one hour and a second one liter sample was taken by very carefully siphoning it off just under the surface of the supernatant. The difference between the suspended solids in the raw sample and in the supernatant sample was recorded as the settleable solids in mg/l.

Total solids from the four ships' samples ranged from 17,200 to 39,800 mg/l with the lower concentrations occuring during evening wash up and shower time and the higher concentrations during earlier morning hours. Total dissolved solids concentrations ranged from 27,100 to 39,200 mg/l. Suspended solids ranged from 18 to 216 mg/l and settleable solids were from 10 to 198 mg/l with a four composite average on one destroyer of 90 mg/l and on each of two repair ships of 53 mg/l. The average of ten determinations on the three ships was 68 mg/l.

Oil Slicks–Note Boat Wakes

Results of typical physical analysis on a three hour composite sample from a destroyer show 35,100 mg/l dissolved solids, 63 mg/l suspended solids, 54 mg/l volatile suspended solids and 18 mg/l settleable solids.

The five-day 20°C biochemical oxygen demand (BOD_5) levels found were on the low end of the range for a typical domestic sewage (9). On this basis the waste would be classed as a weak domestic sewage. These lower levels were due partly to the incomplete breakup of the sewage solids. The lower bacterial levels may also be attributed to this factor. The bacterial die-off resulting from introduction of the bacteria into cold saline water also contributed to the low bacterial levels.

The strength of the wastes varies considerably from ship to ship. This is probably a function of the hydraulics of the disposal system. Most ships are equipped with flush-valve mechanisms for the toilets and the urinals run continuously. The variability encountered depends to a large extent upon how the valves are adjusted.

Floating Material

Other wastes observed were floating materials such as garbage, oil, litter and debris. Although discharges of these materials from ships are prohibited, oil slicks, floating garbage and trash are frequently in areas of vessel activity. Oily substances often observed were observed in association with perlite, an oleophylic material used by the local kelp processing industry.

Total Pollution Load

The estimated total input of pollution from vessels from each source area is shown in Table 6. The military values are based on an average weekday population (10,500 persons) and the waste characteristics shown in Table 5.

A comparison was made of BOD, total coliform, settleable solids and nutrient loads from vessels in San Diego Bay (Table 6) with those from Westgate and Kelco (Table 3, Section V). These two industries discharge tenfold more phosphate, 124 times as much BOD, 173 times as much settleable solids, nearly 200 times as many total coliform and nearly a thousandfold more nitrate nitrogen than is discharged from vessels.

Considering vessel pollution loads only, the military sources similarly overshadow commercial and recreational watercraft sources.

Table 6

ESTIMATED AVERAGE DAILY VESSEL POLLUTION LOAD

Pollutant	Military[1] Naval Station	Carrier Basin	Submarine Base	Mooring Buoy	Total[1] Military	Total[2] Commercial	Total[3] Recreational
Total coliform bacteria x 10^{-10}	1,300	330	186	148	1960	27.8	2.78
Fecal coliform bacteria x 10^{-10}	582	147	82.7	66	8.0	12.4	1.24
Biochemical oxygen demand, 5 day 20°C, lbs	190	48.2	27.1	21.6	287	4.1	0.4
Ammonia nitrogen, lbs	15.5	3.9	2.2	1.8	23.3	0.3	0.03
Nitrate nitrogen, lbs	0.8	0.2	0.1	0.1	1.3	—	—
Kjeldahl nitrogen, lbs	116.0	29 5	16.5	13.2	175	2.5	0.2
Ortho-Phosphate, lbs	23.8	6.1	3.4	2.7	36.0	0.5	0.1
Total phosphate, lbs	38.4	9.7	5.4	4.4	57.9	0.8	0.1

1. Based on average weekday population figures.
2. Based on a population equivalent of 150 man-days per day.
3. Based on a population equivalent of 15 man-days per day.

VII. EXISTING WATER QUALITY

The present water quality of San Diego Bay is summarized below and where appropriate, comparisons are made with historical conditions and with pertinent water quality standards.

Temperature

Water temperatures during the study period varied seasonally from a monthly average of 14.1°C during January, 1967, to 24.1°C during August, 1967. During the winter the temperatures were quite uniform over the entire bay, and were essentially the same as those noted at a reference station in the ocean. These temperatures were in the range of 13.5–16.5°C. In March, 1967, a gradient was noted with higher temperatures at the southern end of the bay. From May through August, this gradient remained relatively uniform with an increase of about seven degrees Centigrade from the bay entrance to the upper end of the bay. During this same period, the monthly average temperature increased from 15.6°C to 20.8°C near the entrance and from 23.4°C to 27.1°C in south bay. A high vertical temperature gradient was not observed. In the deeper portions of the bay, the difference between surface and bottom temperatures is on the order of one to two degrees Centigrade.

Salinity

Salinities for San Diego Bay averaged 33.8 parts per thousand (ppt). Data for the ocean reference station over the same period had an average salinity of 33.2 ppt. Seasonally, the lowest salinities were found in March and April, with an average of all stations of 33.3 ppt. With the exception of far south bay, which had an average salinity of 33.7, the values in the bay ranged between 33.1 and 33.3 ppt during March. During the summer and fall the overall average was 34.1 ppt with a high of 35.0 ppt at the south end of the bay.

Transparency

Water transparency in the bay, as measured by Secchi disc, ranged from an average of thirteen to fifteen feet near the entrance to lows of seven to ten feet in the U. S. Naval Station and other parts of south bay. Confined, relatively shallow areas such as Glorietta Bay and the basins behind Shelter Island and Harbor Island also had average transparencies in the seven to ten foot range. The average transparency for the ocean reference station was twenty feet.

Seasonally, the lesser transparencies were found during the spring and summer months. This reduction was believed due to an increase in biological turbidity, following a pattern similar to that of many other water bodies.

The transparencies observed compare favorably with the standard for transparency adopted by the San Diego Regional Water Quality Control Board. This standard states that the transparency, to the extent that it is influenced by any controllable factor, shall not be less than eight-foot; however, for each zone as a whole, transparency exceeds the standard.

Nitrogen and Phosphorus

Average total nitrogen values ranged from 0.30 mg/l at the ocean reference station to about 0.60 mg/l at the southern end of the bay. Total phosphorus averages for the same locations were 0.04 mg/l and 0.11 mg/l, respectively. In both cases, the gradient up the bay was approximately linear. The data did not indicate any localized areas with high nutrient levels.

The nutrient levels found are not considered to be high. In comparison, the average values for nitrogen and phosphorus in San Francisco Bay are about twice those found in San Diego Bay. During the study period excessive growths of planktonic and attached algae were not observed. Apparently, the existing nutrient concentrations were not sufficient to sustain objectionable algal populations. This is in direct contrast to conditions existing prior to 1963, when "red tides" were commonly observed, algal blooms were continuous the year round, and transparencies were as low as one foot.

Floating Material

Oily surface films are frequently found in San Diego Bay. These were observed a total of fifty-eight times during the course of sampling. Of this total, eleven were in the vicinity of the submarine base and the fueling pier on Point Loma, and thirty were located

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in and around the U. S. Naval Station and industrial zone. The majority of these films, or patches, were small in area and very thin. Some, however, consisted of a heavy grade oil and were relatively thick, indicating that bilge water may have been discharged to the bay.

Floating sewage solids were noted eight times during scheduled sampling runs. All of these observations were made in or near the three main military berthing areas with the majority being found in the U. S. Naval Station area. Sewage solids were also observed in other moorage areas on numerous occasions.

Floating garbage and trash occurs primarily along the eastern side of central San Diego Bay. As with sewage solids, the greatest number of sightings was in the Naval Station. These patches generally consisted of small amounts of material. In some cases, however, the winds and currents concentrated it into unsightly patches or streaks.

One other type of floating matter which should be mentioned originates in an industrial process. The kelp processing plant located in the industrial zone uses large quantities of an inorganic filter aid called perlite. This material, in the form of fine granules, is discharged to the bay in large amounts. Perlite is found in all parts of the bay and is readily concentrated by wind action. Combined with oil it creates very unsightly conditions.

View of Perlite Near Shore

Perlite and Oil Off Waterfront

The San Diego Regional Water Quality Control Board has adopted objectives for floating matter which state (3) that,

> "The waters of the bay shall be free of garbage, trash, floating solids, grease and/or petroleum oil slicks, to the extent such material shall not be present in more than two percent of all individual observations."

Excepting within a mile or so at the harbor entrance, all major areas of the bay violate this standard.

Dissolved Oxygen

The dissolved oxygen (DO) data show considerable variation both longitudinally and across the bay. The results, in the form of frequency distribution for various zones of the bay are shown in Figure 5.

The data indicate that the water in Zone V, or north bay, generally has oxygen levels greater than 7.0 mg/l. Only one value less than 6.0 mg/l was observed. Ninety-nine percent of all observations in Zone V were greater than eighty percent of the oxygen saturation value and seventy-seven percent of the observations were greater than ninety percent of saturation. The central bay area, which supports the highest level of vessel and waterfront activity has the lowest DO of any part of the bay. This area is comprised of Zones II, III, and IV. A significant portion of the samples from these zones had DO concentrations less than 6.0 mg/l and in Zone II, the Naval Station area, approximately 10% of the samples were in the range of 4 to 5 mg/l. The water quality

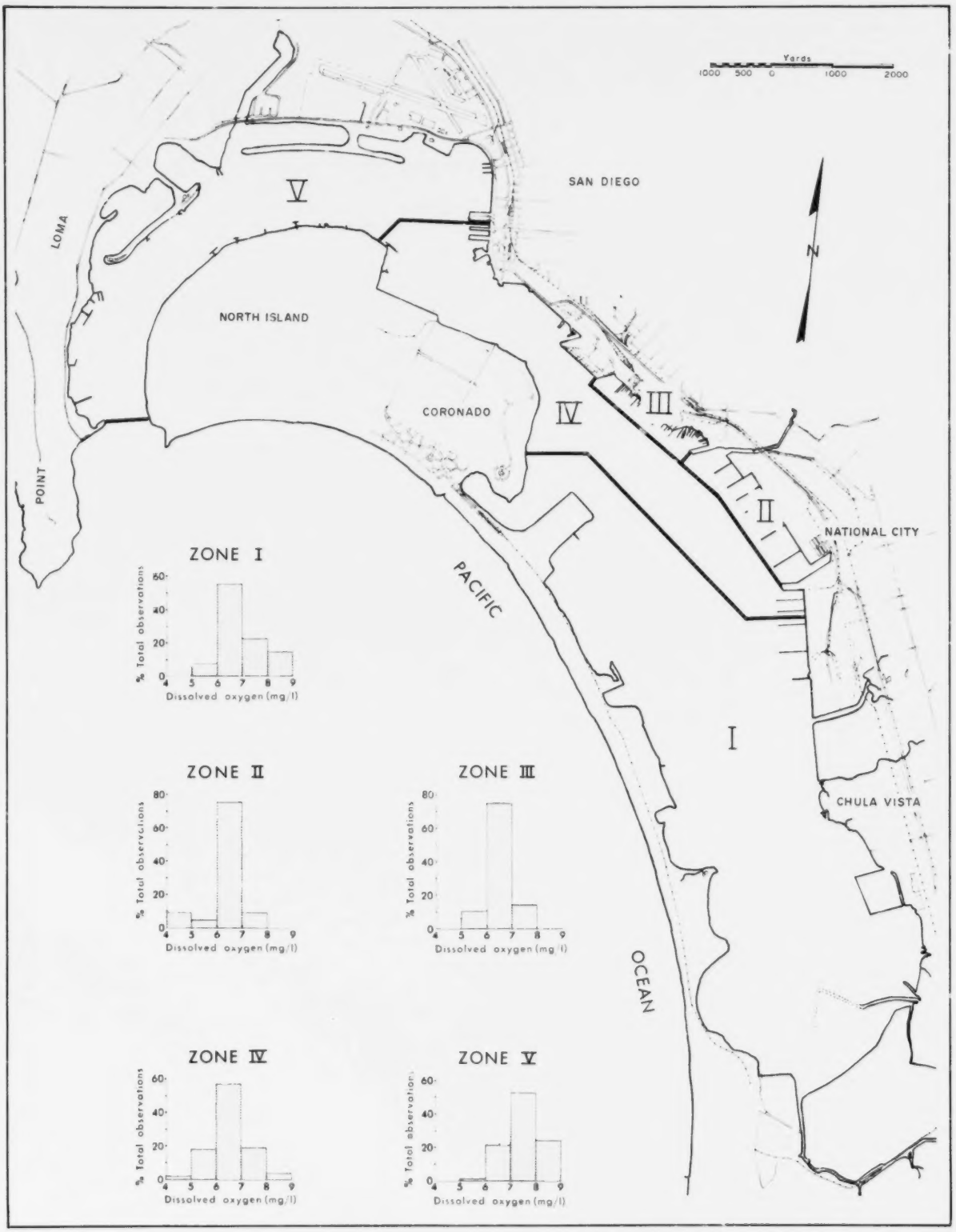


Figure 5. DO Frequency Distribution

standards stipulate that DO shall exceed 6.0 mg/l except in a zone in the general area of Zone III. This DO objective is not being achieved.

Bacterial Density

The bacteriological quality of the bay water was evaluated using four different groups of organisms. These were total and fecal coliform bacteria, fecal streptococci, and Salmonella. After an initial period of sampling in which 632 analyses for fecal strep showed a geometric mean of nineteen organisms per hundred milliliters, this analysis was discontinued. Fecal streptococci densities ranged from zero to 280/100 ml in fair weather and as high as 430/100 ml shortly after heavy rain.

The distribution of total coliform bacteria is shown in Figure 6. The median levels shown are the result of fifteen months of sampling. These data show that median total coliform levels greater than 200/100 ml are confined to a relatively small area of the bay. Values over 1000/100 ml are limited to pockets along the eastern shore. These areas of maximum total coliform levels are about equally divided between the U. S. Naval Station and the waterfront industrial zone. One small area of high concentration near the "B" Street Pier was also located. The maximum bacterial density encountered during the study was 8200/100 ml and was found within the Naval Station. Of 157 sampling stations, thirty, or 19.1 percent, had a total coliform density of 1000/100 ml or over in at least one sample.

The State-Federal Water Quality Standards for the Bay stipulate that the total coliform density shall not exceed 1000/100 ml in more than 20 percent of any 20 consecutive samples at any station. Five of ten sampling stations in the Naval Station area exceeded the standard based on an average of ten station visits.

Fecal coliform levels in the bay are generally low as compared to commonly accepted water quality objectives for recreational water uses. In areas of higher total coliform density, the fecal coliform density ranged between 100 and 500/100 ml with some of the station medians being greater than 200/100 ml, a level which has been suggested as a limit for primary contact recreational waters. (15) The maximum count observed was 2500/100 ml, again at a sampling point in the Naval Station. Maximum fecal coliform counts in excess of 200/100 ml were obtained at 28.7 percent of the regularly visited stations. Special samples taken periodically at a point near the "B" Street Pier had fecal coliform levels as high as 664,000/100 ml. This area receives intermittent discharges from the San Diego Zoo. These levels were confined to a very small area and, therefore, were not included in computations to determine average bay water quality.

The bay was divided into zones to permit statistical analysis of the total and fecal coliform data. The zones used were the same as those shown on Figure 5. The data for each zone were analyzed to see if the zonal means were dependent upon water temperature, phase of the tide, or depth. A positive correlation of bacterial density with these factors could not be demonstrated. Table 7 shows the geometric means for each zone.

Table 7

BACTERIAL DENSITY IN SAN DIEGO BAY

(Number/100ml exceeded in percent of samples shown)				
Zone	**Total Coliform**		**Fecal Coliform**	
	50%	20%	50%	20%
I	3	20	2	9
II	600	2250	170	600
III	770	1403	370	1093
IV	94	463	34	143
V	45	165	8	28

Sampling for Salmonella bacteria was carried out in several sections of the bay. Samples were taken in areas of vessel activity and known bacterial contamination. The results of the analyses are shown in Table 8.

Table 8

ISOLATION OF SALMONELLA BACTERIA

Location (Total Coliform density*)	Number of Samples	Positive Isolations	
		Number	% of Samples
North Island-Carrier Basin (313)	2	1	50
U. S. Naval Station (2250)	14	5	35
Shelter Island Yacht Harbor (61)	5	1	20
Commercial Basin (180)	8	1	13
Industrial Zone (1403)	11	1	9

*Value exceeded in 20% of all samples.

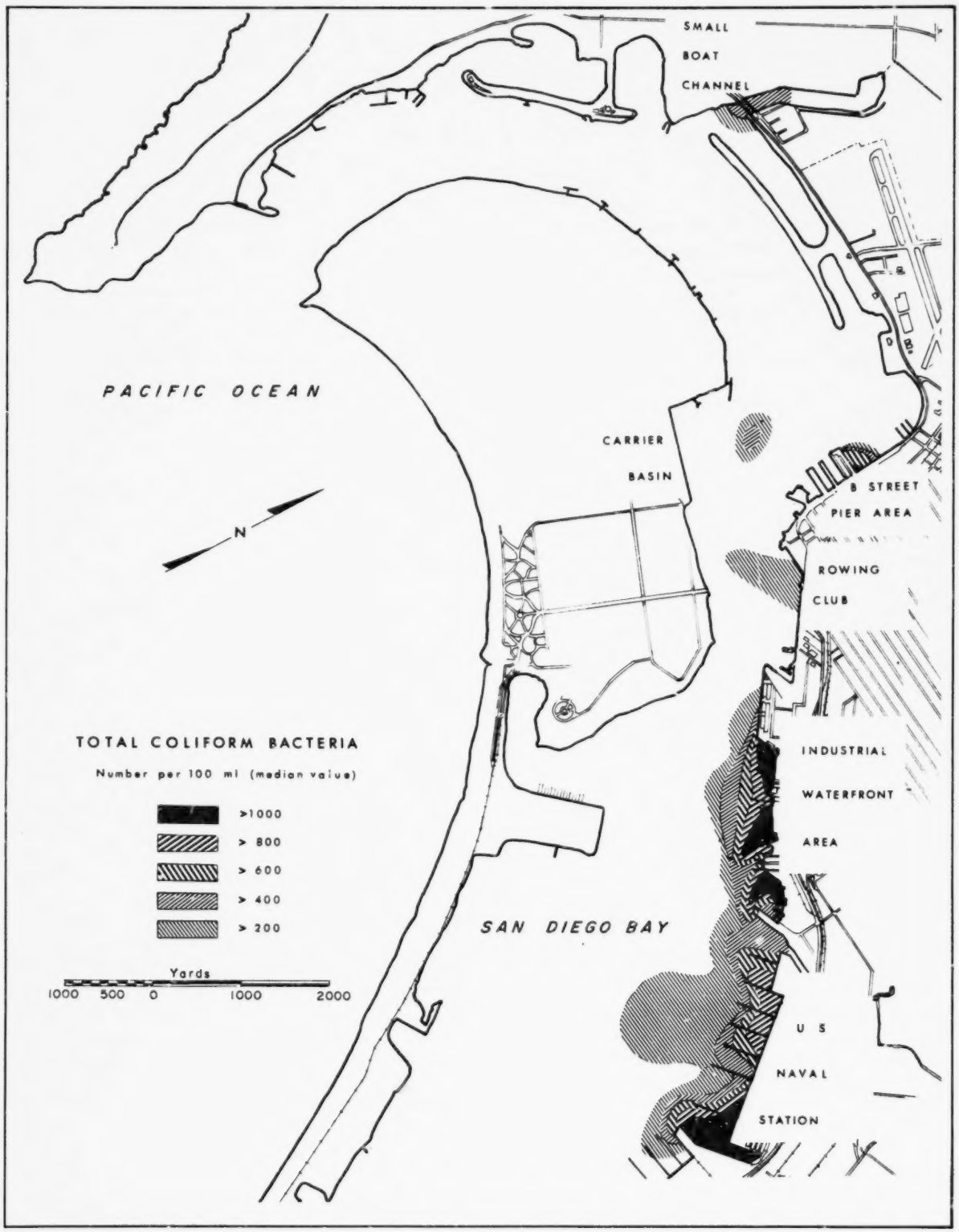


Figure 6. Distribution of Coliform Bacteria

These data show the highest incidence of positive Salmonella isolations are found in areas of concentrated vessel activity.

Biological Conditions

The condition of the benthic environment was evaluated during October 1967. (5) This investigation confirmed that both stable and actively decomposing sludge deposits are present in certain areas of the bay. The central bay area was considered to be the most polluted. In the Reserve Fleet area a two inch layer of decomposing organic material was found and there were fewer organisms present than in cleaner areas. Bottom conditions in the U. S. Naval Station and adjacent channel varied considerably. For example, between Piers 1 and 2 the bottom supported large numbers of a pollution tolerant worms and contained rather high levels of organic carbon in the upper layer while inside the pierhead line of Piers 2 - 8 fewer worms were found and organic carbon levels were typical of decaying deposits. At the pierhead line more kinds of bottom organisms and a more stable sludge layer were found. This gradation of active sludge inshore to more stable conditions beyond the pierhead line was substantiated by observations made by diving biologists.

Analyses of core samples from several points within the U. S. Naval Station revealed a layering of sludge with several inches of fairly stable material overlying a layer capable of active decay.

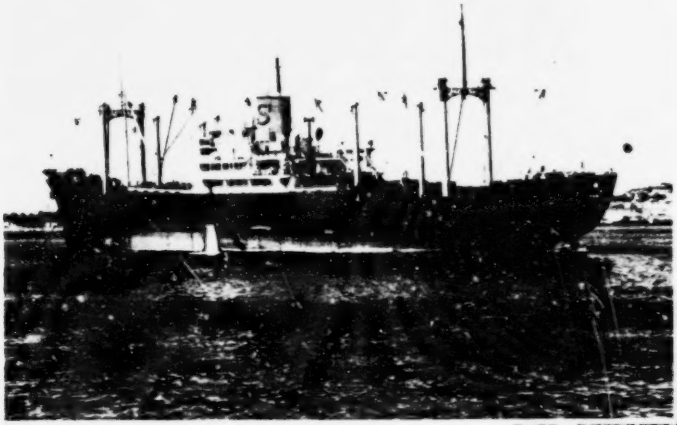
This unusual situation was related to the termination of domestic waste discharges to the Bay. Before 1963, the city of San Diego discharged sewage into the area of the naval piers with the resultant build-up of an extensive sludge bed. Since 1963, the city has discharged to an ocean outfall and the sludge beds in the bay have been receding. If these sludge beds were deposited rapidly, thus preventing aerobic decomposition of carbonaceous materials, they may contain large amounts of decaying matter underneath a top layer of decayed sludge. Also currents caused by the movement of naval vessels in the area may be continually removing the old decayed sludge in some areas and redepositing it over actively decaying layers. The naval pier area in Central Bay contained sludge ranging from 14 to 44 inches in depth. Bottom organisms were predominantly polychaete worms, an indication of moderate to severe organic pollution. Pollution tolerant snails, scuds and shrimp were present where the sludge was partially stabilized. In some areas, actively decomposing sludge with high organic carbon values, ranging from 3.8 to 4.5 percent, covered old decayed sludge that probably was deposited by the city of San Diego before 1963, indicating a continuing contribution to sludge beds from naval ships docked in the area.

In the industrial waterfront (Zone III) bottom samples near the kelp processing plant submerged outfall showed a 16-44 inch layer of black sludge covered with a layer of ground kelp, oil and perlite (filter aid used in kelp processing). The organic carbon and organic nitrogen content of the sludge was typical of actively decaying material. Bottom samples near and offshore from the tuna cannery (Zone III and into Zone IV) showed a soft dark flocculent material overlain by a layer of actively decomposing ooze as thick as thirty inches inside the pierhead line to twelve or so inches in the channel offshore. Indications are that settleable material from the industrial outfalls are deposited close to shore aided by the baffling effect of the piers and to a lesser extent in the channel, and is covering older, more stable, materials which probably are a result of the municipal discharge prior to 1963.

The northern section of San Diego Bay (part of Zone IV and all of Zone V, Figure 5) had localized areas of pollution. Over thirty inches of decayed sludge were found covering the bottom of the Carrier Basin. Since the Basin is ten feet deeper than elsewhere in the bay and since prior to 1963 the city of Coronado sewage outfall was located just to the east, it is logical to assume that this sludge resulted from the municipal waste discharge. It is also logical to assume that settleable solids from ships using the Basin also contribute to the sludge bed.

Elsewhere in Zone V bottom conditions indicating active decay were found near the "B" Street pier (zoo outfall), inside Harbor Island (a result of recent dredging) and within the Commercial Basin in the vessel docking areas. A more stabilized sludge and some debris were found in the Shelter Island Yacht Basin. With the exception of these localized areas, Zone V bottom conditions were typically those of a relatively clean environment.

The diving survey results were in generally good agreement with those stated above. One of the divers had conducted a similar study in San Diego Bay in 1952 and was thus able to compare conditions. He concluded that "the bay appears much cleaner and healthier" than in 1952.



Freighter in Mid-Channel

Commercial
Basin

Fishing
Clipper

Shelter Island
Yacht Basin

In the Naval Station, the divers found a black sludge layer under the piers. In the open area between the piers the bottom material was lighter in color and apparently more muddy. Juvenile sand bass were noted in holes on the bottom. In the area around the pierhead line six species of fish were observed. The types and number of organisms taken from pilings about five feet off the bottom indicate water quality at the pierhead line was not severly degraded.

Of the other areas of the bay examined by the divers the worst bottom conditions were noted offshore in the general area of the tuna cannery and kelp company discharges and at the "B" Street storm drain site. In both areas, however, several species of fish were observed and a moderate diversity of other organisms was evident.

Bacteriological analyses made by the project staff on the upper one-inch layer of sediments from both the Naval Station pier area and the industrial area, each the site of a major sludge deposit, yielded fewer than 100 total coliform bacteria/gram wet weight of sample. Evidently, coliform organisms do not persist in the sludge deposits. This may be interpreted as further indication of the transformation of raw sewage to relatively stable sludge materials.

Plankton

Plankton concentrations measured were confined to the phytoplankton and these were uniformly rather low during this period of time. "Blooms" were absent both from the bay and the nearby ocean, an unusual situation in Southern California waters. The number of genera represented in the samples were also consistently low. Diatoms, in general, dominated the plankton population, both in terms of total numbers of individuals and of genera represented.

It will be noted from Table 9 that the lowest plankton concentrations occurred in early winter (December 23, 1966) and late spring (May 9, 1967) with maximum numbers per liter being less than half a million organisms. These maximums were found at the ocean reference station and in the north part (Zone V, Figure 5) of the bay. Counts in the south and central areas were mostly less than one hundred thousand per liter. In contrast, the summer (August 14, 1967) and fall (October 20, 1967) maximum plankton concentrations were thirty to forty times those found in winter and spring, with the larger numbers occurring generally in the central and southern areas of the bay.

The plankton data were compared to transparencies (secchi disc readings) and to nutrient concentrations measured on samples taken at the same time. No correlation could be observed between plankton counts and the nutrient levels, however there did seem to be a relationship between lower transparencies and higher plankton counts although insufficient data were obtained to make a statistically valid demonstration of this point.

Table 9

RESULTS OF PLANKTON ANALYSES

Date Taken	Number of Samples	Genera Observed	Maximum		Predominant Organisms*		
			No./Liter	Location	Flagellates	Dinoflagellates	Diatoms
12/66	10	17	380,000	Zone V	Unidentified Flagellate	Peridinium	**Lithodesmium* Nitzschia
5/67	12	18	410,000	Zone V	Unidentified Chrysophycean Carteria	Peridinium	*Thalassionema* Thalassiothrix Chaetoceros Biddulphia Cyclotella
8/67	10	17	15,000,000	Zone IV	*Unidentified* Chrysophycean Chrysococcus Chrysomonos	Peridinium Gymnodinium	Chaetoceros Asterionella Thalassionema Cyclotella
10/67	7	19	18,900,000	Zone I	Unidentified Flagellate Chrysomonas Chrysococcus	*Gymnodinium* Peridinium	Asterionella Chaetoceros Cyclotella Nitzschia

*Predominant organism for samples of each series is italicized.

VIII. INFLUENCE OF VESSEL WASTES ON WATER QUALITY

General Considerations

Five of the water quality indicators measured during the study are of significance in delineating the impact of vessel wastes. These are total coliform bacteria, fecal coliform bacteria, Salmonella bacteria, dissolved oxygen and floating matter. The evaluation of the benthic conditions is also of importance.

Evidence of bacterial contamination is provided by the incidence of total and fecal coliform density in areas of concentrated vessel activity and by the presence of Salmonella which are disease-causing or pathogenic bacteria. As pointed out previously, five positive results for Salmonella were obtained from a total of fourteen samples in the Naval Stations. The presence of these pathogenic organisms is considered to be a health hazard to persons coming in contact with this water.

The bacterial density found in areas of vessel activity is due to wastes both from vessels and from other nearby sources. This was clearly indicated by a dye tracer study which was conducted in the Bay during September, 1967 as described in Appendix D. This tracer study showed that on a flooding tide waters from the industrial zone moved into the Naval Station. On ebb tide water from the Naval Station moved in a narrow plume down the east side of the Bay with small amounts entering the industrial zone.

To isolate the vessel waste effects a mathematical model of the Bay was used to aid in estimating the relative contribution from each waste source. This model simulates the hydraulic regime and permits examination of the overall and individual effects of waste loads discharged at various points within the bay. A general explanation of the construction and use of the model appears in Appendix E.

The mathematical model considered average tidal conditions and waste discharge points simulating the Kelco outfall and the afloat population in the Naval Station. Waste characteristics used as inputs to the model were average and maximum flow rates, average and maximum total coliform concentrations, average fecal coliform concentrations and two different coliform disappearance rates. The model studies showed that ninety to ninety-five percent of total coliform bacteria and seventy-five to eighty percent of fecal coliform bacteria in and around the Naval Station came from the Kelco outfall. The difference in these percentages is consistent with the ratios of total to fecal coliform of approximately 5:1 in the Kelco discharge as contrasted with approximately 2:1 in the Naval Station sources. Assuming these results accurately quantify and separate the effects from the two sources it is reasonable to further assume that removal or reduction in flow and strength of the Kelco waste stream will materially reduce fecal and total coliform concentrations in both areas.

The model studies showed that in the absence of the industrial and all other waste sources median bacterial densities of approximately 220 total coliform per 100 ml and 100 fecal coliform per 100 ml could be expected in the Naval Station area due to vessel discharges in all four military anchorages. These densities would be associated with the maximum observed afloat populations of approximately 19,000. It should be noted that these values represent average daily figures for all of the Naval Station waters. Since the waste discharges from these vessels are discreet in time and space, considerable variation from the average bacterial densities cited would be expected to occur in the Bay waters under actual conditions.

It has been noted that the lowest dissolved oxygen concentrations may be found in Zone II, the Naval Station area.

However, the dissolved oxygen concentration in this area is affected by factors other than vessel waste discharges. Two oxygen demand sources which must be considered in evaluating oxygen levels are the decomposing sludge beds and the discharge from Kelco. The sludge beds exert an oxygen demand on the overlying water and the oxygen-consuming characteristics of the Kelco discharge are shown by results obtained using the mathematical model to lower oxygen levels in the central portion of the bay approximately 0.7 mg/l. The effect of vessel wastes on the oxygen resources of the bay is considered to be minor relative to the much greater influence of these two sources.

The benthic environment in the area of the Naval Station is affected by organic pollution. As pointed out in the previous chapter the worst bottom conditions appear in the channel close to the piers and towards the shoreline inside the Naval Station. The sludge in these areas has a relatively high organic carbon content indicating active decay. Some of the open areas between the piers also contain active sludge but others have a more stable bottom as shown by chemical analyses and visual observation. These conditions cannot, however, be attributed solely to vessel wastes, since the main outfall from the City of San Diego sewerage complex was originally located next to Pier 5 within the Naval Station. Heavy vessel traffic around the Naval Station continually stirs up the bottom sediments, as indicated by high turbidity observed during ship movements. Core samples reveal large amounts of both undecayed and stable sludge which are constantly being exposed and resuspended. Settlement of these materials in the calmer waters under the piers and toward the seawall probably accounts for the heavier accumulations in these areas. Wastes from vessels undoubtedly contribute significantly to the adverse bottom conditions; however, the precise extent of this contribution cannot be determined.

Although a major oil spill caused by a ruptured pipeline occurred in November 1968 after formal sampling had ceased, most oil slicks observed on the waters of the bay are attributable to vessel activity. The great majority of observations of floating oil made during this study were in or near vessel anchorage areas. Oil spillage during fueling operations was the usual cause. In general, most of these spills were minor, however, there is often enough oil to create a thin film over much of the central bay area. These films are aesthetically objectionable and reduce the reaeration capacity of the water.

Other floating materials attributable to vessel wastes such as sewage solids, garbage and trash were also frequently observed inside the pierhead line of the Naval Station. Most of the garbage and trash is believed due to carelessness of individuals rather than from ship to shore transfer operations. Small amounts of floatables were observed to move with the wind and tide and combine with other floating material into large mats or rafts which magnify the aesthetic problem. Floating sewage solids represent a health hazard by distributing pathogenic organisms from vessel anchorages to other parts of the bay.

Special Studies

Effects of vessel wastes on bacteriological quality of marine water were further demonstrated by special short term studies in the Carrier Basin and in the Shelter Island Yacht Harbor and Commercial Basin. Background total coliform levels were determined at twelve stations and two depths within the Carrier Basin at a time when no ships had been present for at least five consecutive days. Total coliform counts along the quay wall were less than 40/100 ml. Immediately following the background survey three aircraft carriers with an afloat population of 6,000 were moored along the quay wall. Total coliform level determinations were repeated following arrival of the ships under conditions similar to the background survey five days earlier and increased counts to 500/100 ml were observed along the quay. Thus, untreated wastes from a population of 6,000 men increased total coliform levels in waters immediately adjacent to the ship from forty to 500/100 ml.

Bacterial levels in and adjacent to the Carrier Basin also appeared to be subject to interference from the Kelco discharge. This was partially verified during the dye tracer work wherein the ebb tide "river" of flow past the industrial area appeared to meander from side to side across the main channel. Such a plume of higher coliform levels across the ship channel near the Carrier Basin was suspected from results from the random sampling program and verified in two intensive samplings in this part of the bay. Considering the above, it is concluded that vessel wastes can create significant bacterial densities in the Carrier Basin and these densities can be magnified by industrial discharges on the opposite shore.

Biological conditions on the bottom near the quay wall were indicative of moderate levels of organic pollution. Results of benthic assessments described earlier lead to a conclusion that settleable wastes from observed afloat populations in the Carrier Basin are insufficient to create and maintain the extent of organic pollution found in the Carrier Basin which can be attributed to discontinued municipal waste discharges.

The recreational watercraft moored in San Diego Bay are used primarily offshore. There are no areas suitable for the weekend "boat-ins" that are common along the Atlantic Coast. The large Shelter Island Yacht Harbor is the only area in San Diego Bay where the effects of wastes from recreational craft might conceivably be measured. Routine

sampling and a special survey to assess a maximum use period (July 4th) were carried out. Initial sampling at eight stations in the Yacht basin on June 29, 1967 yielded median total coliform counts of 11/100 ml with a maximum of 550/100. On July 4th, after three days of heavy use, the median count was 13/100 ml with a maximum of 1,200/100 ml. Many more people were observed on board the moored boats on July 4th, although afloat populations were not measured.

This survey gave no indication of large increases in bacterial levels after a long weekend of maximum use. The fact that the marinas have and encourage use of toilet and bathing facilities on shore probably explains the absence of expected increases in bacterial densities.

A special survey over the July 4th weekend in the Commerical Basin showed an increase in the median total coliform density from 70/100 ml on June 29 to 180 on July 4th. No afloat population estimates were made although a marked increase in activity was noted on July 4th.

Water quality sampling was also conducted around single ships at anchor in the bay. The objective of these surveys was to define the waste "plume" from these ships as measured by total coliform bacteria.

The first ship examined was the destroyer U.S.S. Rowan. Normally, a ship of this type has a daytime population of 200-250 men. At the time of the survey the ship was moored to Buoy No. 13 off Harbor Island. A total of eight stations were sampled between 0845 and 0915 at each of two depths. Two stations about fifty yards upstream from the ship were sampled to evaluate the quality of the background water flowing past the ship. The average total coliform count of this water was 240/100 ml. The next three stations sampled were in a cross-section about fifty yards downstream from the stern of the ship. The last three stations were in a cross-section approximately 150 yards from the stern. The data from both of these cross-sections showed no increase in coliform levels. A floating sewage solid was observed on the second transect directly in line with the ship. Cigarettes and other small debris observed indicated the samples were taken in the flow pattern from the ship.

The second single ship survey was somewhat more elaborate than that for the U.S.S. Rowan. Arrangements were made through Commander Service Group One to board the AFS-3 Combat Stores Ship U.S.S. Niagara Falls for the purpose of adding sodium fluorescein dye to the flushing water from one of the head compartments. The plan was to release the dye at a prearranged time through the ship's waste drainage system, observe the dilution and diffusion pattern of the dye in the bay water and to determine coliform concentrations in the dye field as it moved with the tide.

The Niagara Falls has a normal in-port daytime crew of 414 officers and men. On the day of the survey, she was moored for and aft to Buoys 10 and 11 some 250 yards off Shelter Island. At the time of the dye release the tide had been in flood about three and one-half hours, moving into San Diego Bay from the ocean. The head compartment selected contained three stools, four lavatories, two urinals, and two showers, and was located on the main deck. The compartment reportedly serves about forty-five (~10%) of the ship's crew. The waste from this compartment joins that from three other similar compartments and discharges by gravity about midships approximately two feet above the water surface.

Prior to the start of the test, background coliform counts were made upstream from the ship. At 1330 two stools containing visible fecal matter and the dye were flushed and reflushed until color disappeared. The dye was observed entering the bay and was then followed and samples taken until the dye was no longer visible.

The samples taken upstream from the Niagara Falls showed a background level of less than 20 total coliform per 100 ml. The first samples following the discharge were taken about 200 feet down stream from the point of discharge and directly under the stern of the ship. Three to four minutes had elapsed since the appearance of the dye. Total coliform levels had increased to 180/100 ml at the surface and 80/100 ml at a depth of seven feet. Sewage solids and tissue were readily visible. The dye cloud was further sampled at short intervals until it disappeared thirty-five minutes after discharge. In this time it had traveled about 1,500 feet from the ship. The results indicated that after traveling approximately 700 feet the total coliform counts had returned to background levels. These surveys demonstrate that the "plume" from a single head compartment of an individual ship, can be identified bacteriologically in relatively clean marine water.

Related Studies

Few technical references deal with vessel wastes and related water quality. Those available were

reviewed and found to confirm many of the findings of this study. Findings of two of the more relevant studies are summarized below.

The Bureau of Sanitary Engineering of the California Department of Public Health conducted bacteriological surveys of marinas in the San Diego vicinity during a two week period in 1966. (11) On the basis of intensive sampling in Shelter Island, Mission Bay, and Glorietta Bay, the State Health Department concluded the

> "Occasional very high bacteriological counts appear to indicate sporadic discharge of sewage in the small-craft harbors. The need for an additional study in greater detail of all discharges into the bay is indicated."

Since these surveys were completed extensive sampling in the same area by this study has produced comparable results.

The New York-New Jersey-Connecticut Interstate Sanitation Commission conducted a series of surveys in 1953 to determine the effects of cabin cruiser wastes on a sheltered harbor located on Long Island, New York. (12) This anchorage, Eaton's Neck Harbor, is relatively free of external sources of pollution and is used extensively for weekend "boat-ins."

The results of these surveys indicated that weekend "boat-ins" can produce a significant increase in numbers of coliform bacteria in the waters of this sheltered harbor. The total coliform levels did not exceed the commonly applied water quality standard of 1000/100 ml for bathing waters but did exceed, in many instances, the criteria for shellfish waters, i.e. 70 per 100 ml. More important, however, were the reported observations of fecal material.

Future Conditions

The pattern of water quality and bottom conditions in San Diego Bay is expected to change considerably in the future. Control of remaining industrial discharges to the bay is being accomplished by the Regional Water Quality Control Board. This control of shore based activity will serve to isolate the impact of vessels. Increased military vessel activity in the port is expected following any cessation of hostilities or intense surveillance in Far East waters. The impact of a larger military vessel concentration on water quality in the bay is of concern. Predictions were made to quantify the effects of reduced shore based discharges and increased vessel activity.

The port of San Diego will continue to grow as a commercial port; development of planned port facilities and marine terminals will result in larger numbers of ship visits. The master plan of port development shows a second harbor entrance and extensive dredging and construction in the southern end of the bay. Changes in hydraulic characteristics resulting from the dredging and the second entrance will be dramatic and will probably alter considerably the bay's present ecological regime. The dredging may destroy some present fish and wildfowl breeding and nesting grounds and eliminate some shellfishing area in the extreme south end of the Bay.

The water quality in the bay with respect to nutrients and dissolved oxygen should show some further improvement because of the eventual decay of the remaining sludge beds and reduction of industrial discharges. The extent of the sludge beds had been greatly reduced since termination of the municipal discharges in 1963. The old sludge beds will continue to decay and diminish in depth and extent. This decay with attendant nutrient release and oxygen consumption should continue until all the old sludge is either consumed or buried in the sediments.

In late 1967 the San Diego Regional Water Quality Control Board adopted a series of resolutions setting discharge requirements for the industries using the bay for waste disposal. Of particular interest are the requirements for the Kelco Company (13) and the Westgate-California Corporation (14). Kelco is required to reduce the amount of BOD being discharged from 34,000 to 10,000 pounds per day and the settleable solids from 39,000 to 3,100 pounds per day. Company planning is also in progress to treat, for by-product recovery, previously discussed waste stream containing extremely high coliform counts. The tuna cannery is required to limit their discharges to 2,500 pounds per day of BOD and 1,300 pounds per day of suspended solids. These modifications were scheduled for completion by late 1968.

Implementation of these requirements and plans will reduce settleable solids and bacteriological loadings. Bottom conditions will improve as the amount of settleable solids discharged is reduced. Mathematical model studies indicate that cessation of the Kelco discharge will probably reduce total coliform concentration to less than ten percent of

the present levels in the central areas of the bay. Fecal coliform levels will also be reduced, by approximately seventy-five percent. As previously indicated, the number of total coliform bacteria discharged into the bay by Kelco is over 100 times greater than the number originating from all vessel sources. It is likely that all areas of the bay will meet the bacteriological standards currently adopted by the Regional Water Quality Control Board.

The effect of larger numbers of ships will be increased bacterial levels in waters immediately aound the ships and a consequent increased health hazard to persons coming in contact with those waters. With all military anchorages completely full, it is estimated that over two-hundred ships and about 38,000 persons would be afloat in San Diego Bay. This condition is highly unlikely because of security and current limitations on the number of ships that could be assigned to San Diego at the same time. However, mathematical model simulations of the effect of maximum observed populations (approximately 19,000) in all four military anchorages shows concentrations of total and fecal coliforms due to vessels would be approximately 220 and 100 per 100 ml, respectively. Maximum possible afloat populations (38,000) would double the above figures. The higher populations would also increase the probability of isolating Salmonella bacteria from the bay waters.

The effect of increased vessel activity would increase the probability of observing floating sewage solids unless adequate water pollution control measures are instituted. Deposition of organic wastes from increased vessel activity would contribute to the existing sludge deposits.

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APPENDIX A. SAMPLING METHODS

Water Quality Samples

The sample collection system used during the study was designed to allow a maximum number of samples to be taken as well as processed in the field. The system is comprised of a weighted, fifty-foot vinyl hose, a centrifugal pump, and a transparent plastic mixing chamber. Figures A-1 and A-2 picture the sampling train. For sampling the hose was lowered to the desired level and the pump started. Water passing through the pump was discharged into the bottom of a mixing chamber. Excess water flowed overside through the top of the chamber via a length of vinyl hose.

Water samples and physical measurements, except for transparency, were taken directly from the mixing chamber. One hundred milliliter bacteriological samples were collected from the chamber overflow into calibrated cylinders. Smaller aliquots were withdrawn via a sampling port connected by small diameter tubing to a valved repetitive syringe. Dissolved oxygen and temperature measurements were taken from sensing probes inserted into the top of the mixing chamber (not shown in figure). Bottles for comparative Winkler dissolved oxygen determination were filled from the same tubing and used for the smaller bacterial aliquots. Samples for chemical analyses were collected from the chamber overflow. For salinity determinations the mixing chamber overflow was conducted through large diameter plastic tubing into a holding tank mounted on the transom of the boat. The tank, provided the large volume of water required for total immersion of the induction coil of the salinometer employed, and was drained between stations.

Sampling for Waste Characterization

Collection of samples of sanitary waste discharges from large vessels presented problems. The only feasible sampling point was where the waste discharges through ports in the hull. These ports, generally several on each side of a ship, are between eighteen inches and three feet above the waterline, too low for adequate collection from the ship itself. Collection from a floating platform was hazardous because of the continual wave action created by winds and passing vessels and collection from a stable platform such as a dock or pier was complicated by the rise and fall of the tide. None of these problems were overcome.

A receiver that would intercept the entire flow from one outlet was designed to hang on the outside of the ship. Threaded nuts of brackets welded to the ship's hull on each side of the outlet pipe were utilized to support the receiver frame. These nuts or brackets may be found at all sanitary waste outlets on most ships. They are installed so that a flexible pipe may be connected to the outlet to carry the wastes away while the ship is in drydock.

The receiver itself was a twenty-gallon plastic bucket set in a framework of metal strap and angles assembled so that bucket height and distance from hull was readily adjustable. A toilet tank ball valve installed in the bottom of the container permitted rapid draining. Figures A-3 and A-4 picture the receiver and frame mounted and in operation on the destroyer U.S.S. Morton, DD-948.

The design of the receiver permitted collection of a sample proportional to total flow. All wastes from the single outlet were intercepted and when the wastewater reached the twenty-gallon mark on the receiver bucket, the contents were stirred and a fifty milliliter aliquot was taken, after which the flush valve was immediately tripped to drain, then closed and the procedure repeated. The aliquots were composited for two hours when portions were withdrawn for bacteriological analyses. The remainder was stored under refrigeration for later physical and chemical analyses. This process was then repeated.

Physical and chemical analyses were performed on six or eight hour composites and BOD tests on twenty-four hour composite samples.

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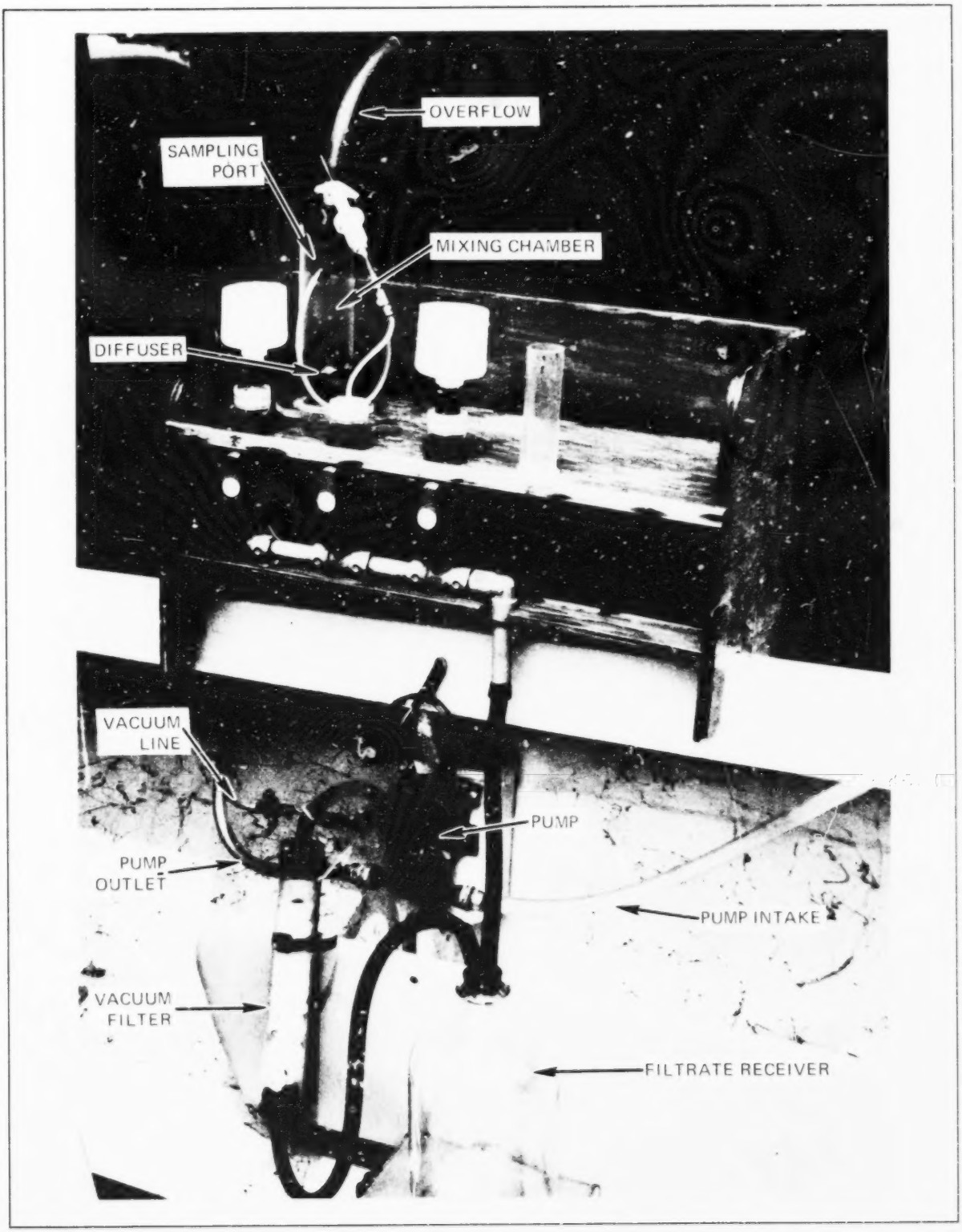
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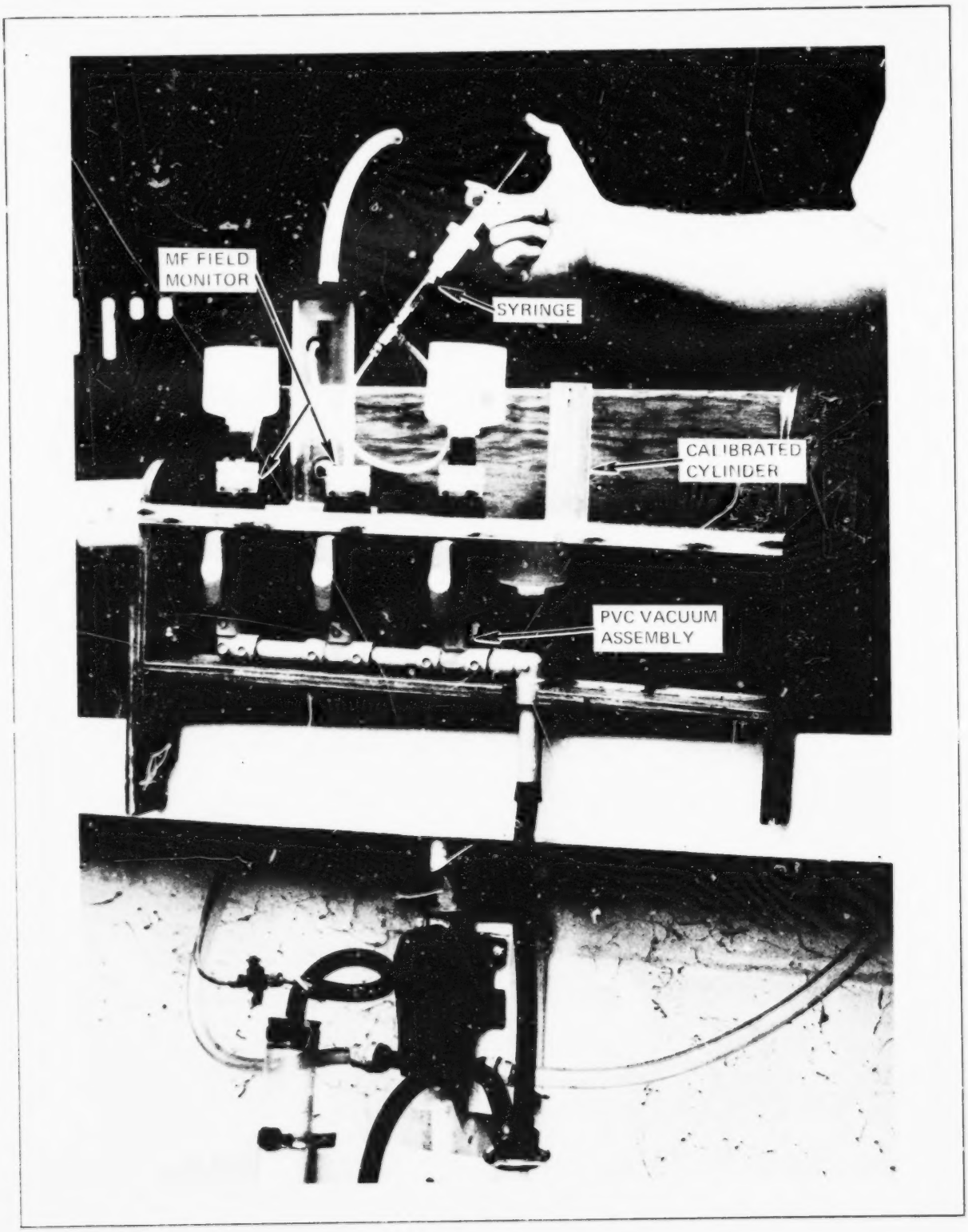
MIXING CHAMBER
DIFFUSER
VACUUM LINE
PUMP
PUMP OUTLET
PUMP INTAKE
VACUUM FILTER
FILTRATE RECEIVER

Figure A-1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CALIBRATED
CYLINDER
PVC VACUUM
ASSEMBLY

Figure A-2

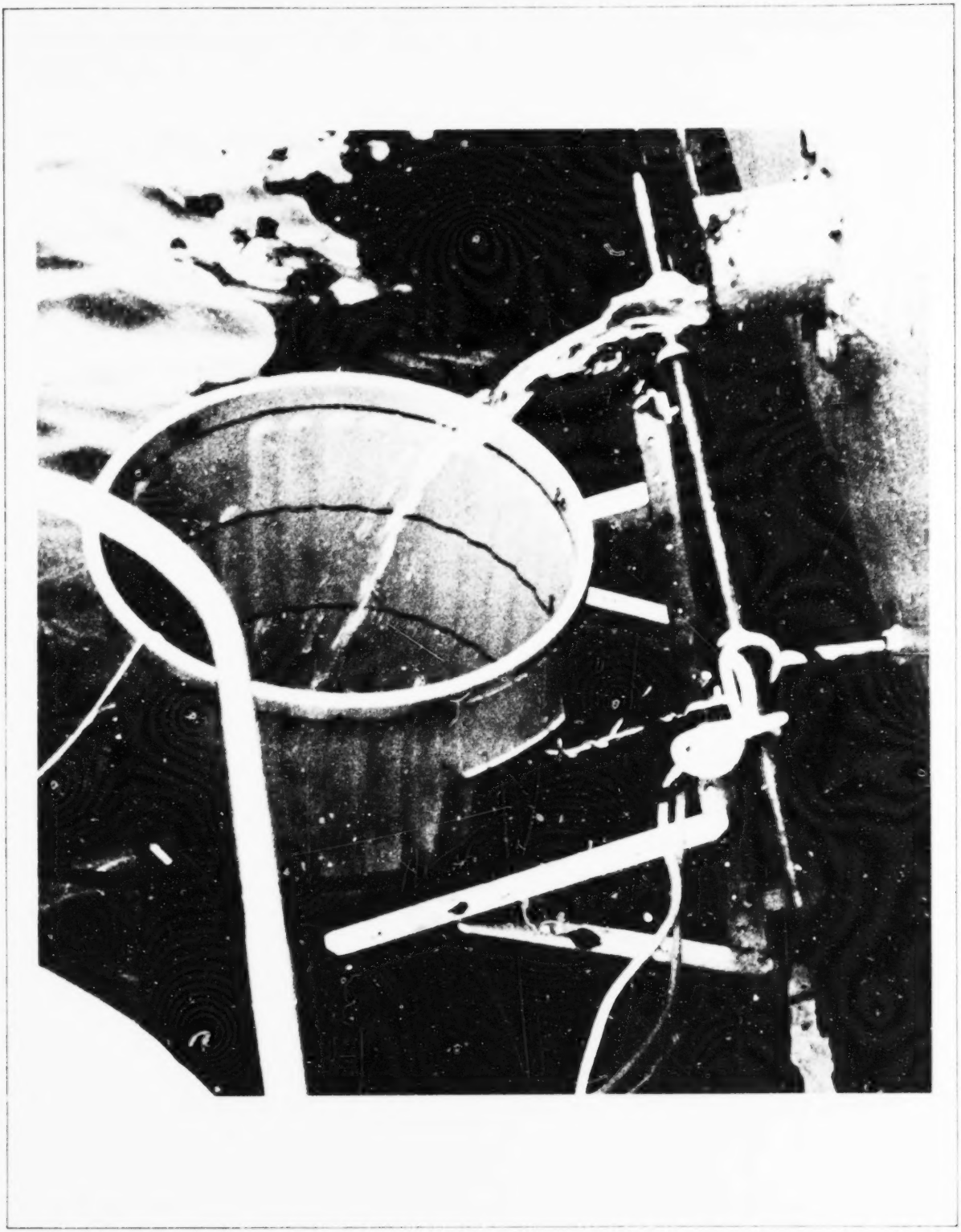

Figure A-3

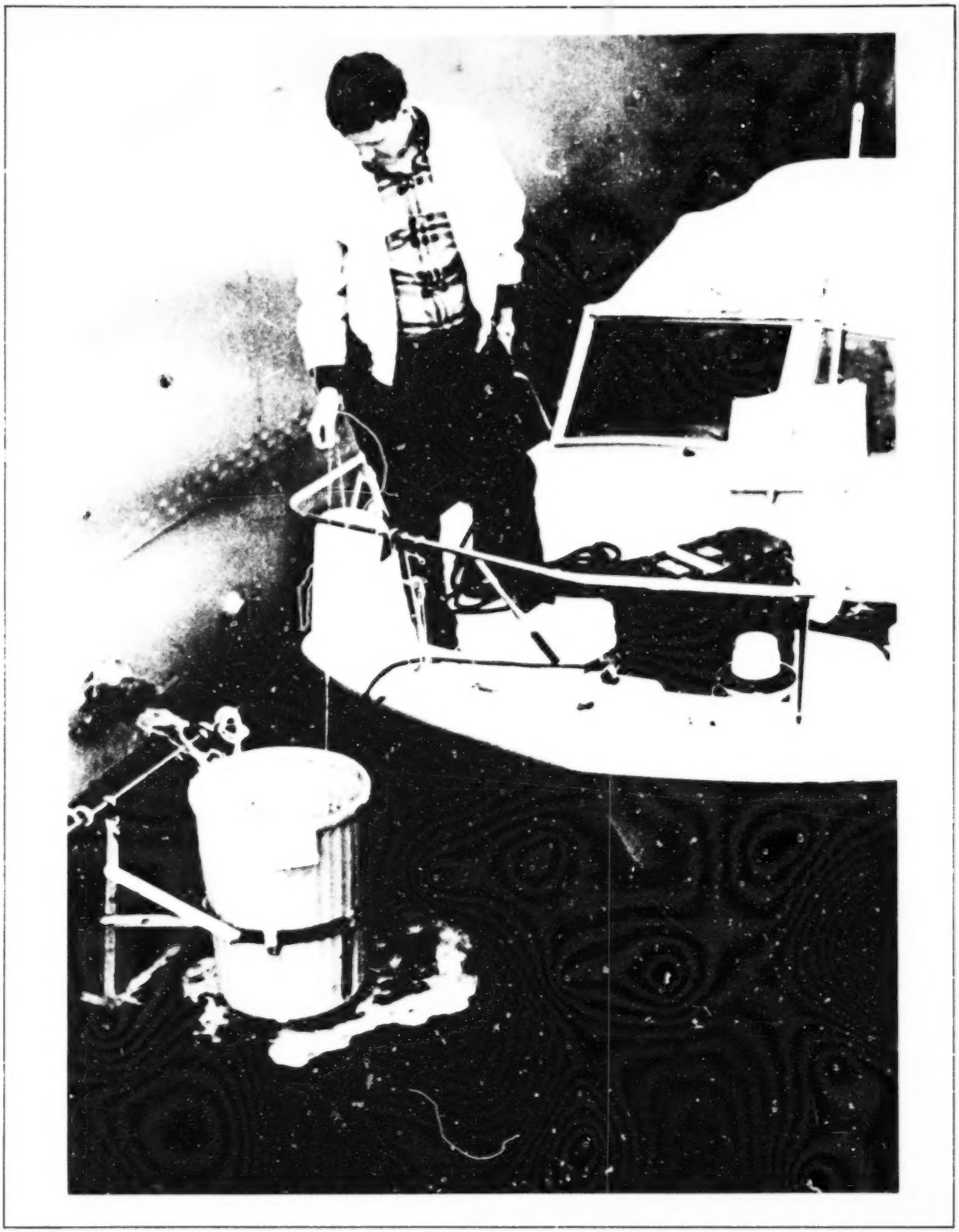

Figure A-4

APPENDIX B. ANALYTICAL METHODS

Chemical

All methods used were those recommended in *Standard Methods for the Examination of Water and Wastewater* (1). Phosphate determinations were made by the stannous chloride method. Nitrate was determined by the brucine method. Analyses were performed by the Pacific Northwest Water Laboratory, Federal Water Pollution Control Administration, Corvallis, Oregon.

Plankton

Samples were concentrated by settling for forty-eight hours or longer in the dark. A ten-fold concentration was made on all samples. One ml was counted in the standard Sedgewick-Rafter chamber at 200X. Two strips were counted. Each single cell or natural aggregate was counted as one unit. Smaller forms were identified at higher magnifications.

Bacteriological

Bacteriological procedures used in this investigation include tests for "total coliform", "fecal coliform" and "fecal streptococcal" bacteria in water, differentiation of coliforms (IMViC) and procedures for enrichment for, and isolation of, pathogenic Salmonella bacteria and enteroviruses. Methods employed were, in general, those recommended in *Standard Methods for the Examination of Water and Wastewater* (1). For the "fecal coliform" test, the procedures and media specified by Geldreich, et. al. (2) were used. The "swab" technique and elevated temperature specified by Spino (3) were employed for detection and isolation of Salmonella strains. Salmonella were identified to species by the Department of Public Health, State of California. The "swab" technique and concentration of virus by ultracentrifugation were employed in unsuccessful attempts to isolate enteroviruses from bay waters. The laboratory of the Department of Public Health, San Diego, carried out the latter tests.

In some details, methods employed in this study for the routine analysis of water for indicator fecal organisms were slight modifications of those commonly practices (1). The following is a list of the modifications employed:

1. Use of membrane filter field monitors in place of the standard membrane or multiple tube (MPN) technique.
2. Direct filtration of water samples while on station in the field rather than collecting and storing water samples for processing in the laboratory.
3. Use of LES agar medium (4) instead of m-Endo medium for the total coliform test.
4. Use of air type field incubators for initial incubation of fecal coliform plates while in the field rather than following the recommended procedure of immediate incubation in a water bath.

Results obtained using the modified procedures are comparable or superior to those obtained with standard methods. Further justification for the modifications is their use makes it possible to significantly reduce both the time and materials required for performing these routine analyses. A need for taking and processing large numbers of samples in a short period of time under field conditions prompted development and adoption of the modified procedures. In the course of their development tests were made to compare the results of the modified procedures with standard methods. A discussion of the results of these tests together with comments on the advantage gained by employing the modifications is given below.

The sampling method described in Appendix A employed field monitors. There are definite advantages in their use. They are convenient and easy to use in the field. Manipulations of the membrance filter prior to filtration are eliminated. Aseptic technique can be employed. However, used as directed they do not give as high counts as the standard membrane filter. It was found, however, that taking apart the plastic container and removing the filter to a petri plate of appropriate medium instead of adding media to the monitor gives results indentical to those from standard membrance filters. The transfer can be readily accomplished in the field allowing the filter to be immediately placed under incubation.

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The main objection to the field monitor is its cost, which is about five times that of standard filters. This work showed that work output can be more than doubled by using field monitors and the described sampling procedure, thus offsetting the additional cost of materials. The monitors can also be sterilized and reloaded to reduce their cost be approximately one-half.

Processing of samples in the field provides several advantages. The need for sample bottles is eliminated and the possibility of loss of samples through breakage avoided. Bacterial density changes which may occur in samples between the times of collection and analysis are also eliminated. Sampling as described in Appendix A also reduces handling of samples to a minimum. The sample is thoroughly mixed as it flows through the pump impellers and the mixing chamber of the sampling apparatus which permits it to be directly dispensed by syringe for small aliquots, or by calibrated vessel for larger samples for the membrane filter. Cross contamination between samples is prevented by thoroughly rinsing funnels and calibrated vessels with the water being sampled. A continuous flow from the pump provides more than adequate rinse water for flushing the entire sampling system as well as the filtration apparatus, thus eliminating the need for sterile rinse water or large numbers of filter funnels. Use of a repetitive syringe eliminates the need for pipettes except where aliquots smaller than two ml are required. One additional, but less obvious, advantage of the method is that replicate samples are true *replicate* samples and not aliquots from a *single* sample, which from a statistical standpoint provides a somewhat more precise estimation of bacterial concentrations.

Three series of tests were made to compare the standard five tube MPN technique with the modified MF (membrane filter) method with three replicates. Water for MPN analysis was taken at the same time that filter samples were taken. MPN tests were completed within one hour of the time samples were taken. Ninety-seven percent of the membrane filter values, computed as the means of three replicates, fell within the ninety-five percent confidence limits about the mean of the MPN results. Values not falling within these limits were slightly lower than the comparable MPN value. These results compare very favorably with results reported by others, including comparisons made using San Diego Bay water (5). Comparing results of the modified MF procedure with standard MF using m-Endo medium showed the modified procedure to give consistently higher results, on the average twenty-five percent higher. In the modified method the enrichment procedure described in the original technique (4) is not used since it was found the method gave comparable results without employing enrichment. Results of comparisons actually showed slightly higher values when enrichment was omitted. These results may probably be attributed to the more prompt processing of samples. The high percentage of fecal coliform to coliform observed, a mean of 36% for 840 samples, gives confidence the somewhat high results obtained are not spurious. Positive verifications of typical colonies from plates occurred in thirty-four percent of those tested using these techniques.

It is necessary in the modified procedure to incubate fecal coliform test plates in air type field incubators for a period of up to two hours before they can be transferred to water baths. This practice has been questioned by other workers who are aware of the critical nature of the temperature requirement for the test. Results obtained in this study were in fact somewhat higher than those from replicate samples analyzed in the laboratory in the conventional manner. Direct comparisions between this increase was in no case more than ten percent and the average being 6.8 percent higher. Verification by the Eijkman elevated temperature test of typical colonies from the samples tested occurred in seventy-five percent of colonies using the modified procedure and seventy-two percent for the conventional technique. Verification of colonies taken from routine fecal coliform analyses was established in 243 of 335 colonies, or 72.5 percent. In view of the above, it is believed initial air incubation is an acceptable procedure. However, the use of a water bath for incubation in the field is desirable, a portable water bath suitable for field work is being developed at the Pacific Northwest Water Laboratory, Federal Water Pollution Control Administration, Corvallis, Oregon.

Kelp Waste

The major source of coliform bacteria in San Diego Bay is the waste discharged during the processing of kelp by a bayside industrial plant. This discharge contains large numbers of fecal bacteria. These apparently do not result from a high fecal contribution to the effluent but instead from bacterial growth which takes place in the initial phases of processing. Preliminary treatment of kelp involves chopping and washing the plants.

Washing is done with hot water to facilitate leaching of slimes.

Chopped kelp mixtures are held sometimes as long as three days at elevated temperatures. Leach and washwater discharge temperatures range from thirty-five to forty-five degrees centigrade. This water, a mixture of salt water from the kelp and fresh water added to it was reported (R) to contain up to 240,000,000 confirmed coliforms (MPN)/100 ml. Average discharge was estimated at 1.4×10^{16} total coliforms/day. In the course of confirming this information it was found that the discharge contained fecal coliforms and fecal streptococci as well, as shown below

Total Coliform (TC) – 7,100,000/100 ml

Fecal Coliform (FC) – 590,000/100 ml

Fecal Streptococcus (FS) – 29,000/100 ml

Compared to the average domestic sewage content this waste is proportionally high in TC and low in FS. Table B-1 shows a comparison between the ratios found in both wastes.

TABLE B-1

Kelp Discharge	Domestic Sewage*
FC/TC (%) 8.3	93.3
FC/FS 20.3	4.3

*Refer to (9).

Further investigation revealed that nearly all the coliforms in the kelp waste were non-fecal in origin. Of one hundred typical colonies from total coliform determinations, only ten gave a positive Eijkman test. Only 29.8 percent of typical fecal coliform colonies from the kelp processing discharge gave a positive Eijkman test as compared to 72.5 percent for samples from bay waters excluding the area near the kelp processing discharge. Classification of eleven isolates giving positive Eijkman tests by their IMViC reactions showed none with the characteristics of *Escherichia coli* or closely related fecal coliforms.

Bacterial Death Rates

The rate of coliform bacterial die-away was estimated for San Diego Bay waters. In two such tests under field conditions the twenty-four hour die-away for total coliforms was estimated at 79.2 percent at twenty-four degrees Centigrade water temperature and 82.7% at seventeen degrees Centigrade. Both are equivalent to a ninety percent die-away of 1.1 days. Nussbaum and Garver (6) have reported a ninety percent die-away rate of 1.4 days, approximately twenty-two percent higher than the results of this study. As pointed out by Orlob (7) however, apparent die-away rates are greatly influenced by the surface to volume ratio of the container employed. Nussbaum and Garver used small volumes of water in dialysis bags in their study and it is probable that surface activity resulted in the slight regrowth of coliforms experienced in their study. The system used in these studies was of much greater volume, i.e. five gallons of water in each of two duplicate polyethylene bags, which hopefully minimized surface effects. Significantly, these studies showed no regrowth over an observation period of ten days.

Salmonella Isolation

Seven species of Salmonella were isolated at least once from waters of San Diego Bay. Following is a list of those found.

Salmonella cubana
Salmonella lexington (isolated on four occasions)
Salmonella derby
Salmonella bredeney
Salmonella infantis
Salmonella gaminara
Salmonella kentucky

Most of these were isolated from the waters of the Naval Station berthing areas where coliform counts were moderately high. However, *Salmonella kentucky* was isolated from the Commerical Yacht Basin and *Salmonella gaminara*, from the Shelter Island Yacht Harbor where coliform counts were consistently low. A survey of these areas during a fourth of July holiday, a period of maximal recreational boat use, yielded coliform counts as follows:

Shelter Island TC–2 to 550/100 ml, median, 10
FC–1 to 160/100 ml, median, 7

Commercial Basin TC–7 to 340/100 ml, median, 120
FC–3 to 200/100 ml, median, 10

The above constitutes convincing evidence that pathogenic bacteria such as Salmonella may be detected in waters of low fecal coliform content.

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APPENDIX C. AFLOAT POPULATIONS

Military Vessels

The population on board military vessels in port fluctuates widely for a variety of reasons. Many personnel maintain residences on shore and spend only duty hours on board. An appreciable amount of on-shore training is conducted with a considerable variability from ship to ship. Leave policies vary widely. Proximity to payday is a factor affecting the number of personnel on board after duty hours. Minimum allowable on-board complement differs among the several operational fleet commands. An estimate on-board population for a given day or time period under these conditions is, therefore, apt to be less than precise.

Man-days of occupancy was used as the basis for developing a meaningful population figure for watercraft. Determination of this directly required the estimation of total number of man-hours a crew spends on board in any twenty-four hour period, and division of the total by twenty-four to obtain man-days of occupancy for that ship for that day. With the large number of ships involved developing these daily figures proved far too time consuming, so a practical compromise was reached. Estimates for the average man-days of in-port occupancy for each type of vessel was obtained from personnel officers of each type command. These estimates were based on normal naval in-port procedure and policy of each command. The figures were then applied to the daily ships-in-port listing published by the Navy. This approach was followed in developing U.S. Naval population figures for the San Diego Bay Study.

There are five naval ship-type commands which have operational control over the military vessels using San Diego Bay. These are:

1. Service Group One
2. Cruiser-Destroyer Force
3. Air Forces
4. Amphibious Forces
5. Submarine Flotilla One

Information was obtained from each of these commands regarding the population on the various types of ships under their jurisdiction. This information included the assigned complement, the average percentage of this complement on board during a typical workday, the length of the average workday, the minimum allowable on-board complement, the average percentage of assigned complement on board during non-working hours, and variations between weekdays and weekends. From these figures an average population equivalent, in terms of man-days of occupancy, was calculated for each ship type for both weekdays and weekends. Table C-1 lists the ship types and corresponding populations developed by this method.

Information on the number, type, and location of ships present on a daily basis was obtained from the Operations Division of the Eleventh Naval District Headquarters. The Fleet Support Section of this division publishes a list of all the ships in port giving their name, type, anchorage location, and arrival or departure time where pertinent. During the study period, this list was available for four or five days a week. The combination of these data with the population figures for each ship type permitted the calculation of a population equivalent for each anchorage area on a daily basis. This was done for a period of record from August, 1966 through July, 1967. The summary of these data appears in Section VI, Table 4.

Maximum possible ship numbers and equivalent populations were developed based on total number of berths in each anchorage area and on observed maximum day average populations. For example, waterfront operations personnel report one-hundred twenty berths in the Naval Station. During the study period for which records were kept the maximum number of berths in use at one time was sixty-six corresponding to a population of 10,000 persons. Application of the average maximum day population to the one-hundred twenty berths resulted in a population of over 18,000 persons. Similarly, during the period of record, the maximum observed population in the Carrier Basin was 4,850 for five ships, only one of which was a large carrier. With all seven berths occupied by ships such as those observed, a population of over 6700 people would be present. Later in the study, however, three large aircraft carriers occupied the entire quay wall at the Naval Air Station, a very unusual situation. On board these ships were

Table C-1

NAVAL VESSEL POPULATIONS

Description	Designation	Assigned Complement	Average Weekday Occupancy, man-days	Average Weekend Occupancy, man-days
Service Group One				
Repair ship	AR-22	650	366	227
Repair ship	AR-8	682	384	238
Oiler	AO	263	240	180
Ammunition Ship	AE-#'s 20 and over	287	270	203
Ammunition Ship	AE-#'s less than 20	180	160	123
Fleet stores	AF	185	155	133
Fleet tug	ATF-100	106	59	40
Fleet tug	ATF-all others	75	43	28
Ocean tug	ATA	106	59	40
Cruiser-Destroyer Force Pacific				
Heavy cruiser	CA	920	484	294
Guided missile heavy cruiser	CAG	920	484	294
Guided missile cruiser	CG	800	421	256
Guided missile light cruiser	CLG	800	421	256
Destroyer	DD	260	137	83
Guided missile destroyer	DDG	260	137	83
Radar picket destroyer	DDR	260	137	83
Guided missile frigate	DLG	320	168	102
Escort ship	DE	160	94	51
Guided missile escort ship	DEG	160	84	51
Rescue escort	PCER	25	14	8
Motor gunboat	PGM	25	14	8
Destroyer tender	AD	900	474	288
Naval Air Force Pacific				
Attack aircraft carrier	CVA-61, 63, 64	2,940	1,709	1,060
Attack aircraft carrier	CVA-43	2,380	1,368	833
Attack aircraft carrier	CVA-65	3,460	1,988	1,210
Attack aircraft carrier	CVA-14,19,31,34,41	1,750	1,000	612
Support aircraft carrier	CVS	1,750	1,000	612
Seaplane tender	AV	685	395	240
Amphibious Force Pacific				
Attack cargo ship	AKA	295	155	89
Attack transport	APA	355	187	107
Amphibious force flagship	AGC	510	268	158
High speed transport	APD	170	89	51
Amphibious transport dock	LPD	370	194	111
Dock landing ship	LSD, #'s 1-27	270	142	81
Dock landing ship	LSD, #'s 28-35	300	158	90
Amphibious assault ship	LPH	560	294	168
Tank landing ship	LST, #'s 1158, 1168	140	74	42
Tank landing ship	LST, all others	110	58	33
Landing craft repair ship	ARL	140	74	42
Submarine Flotilla One				
Submarine tender	AS	1,000	428	428
Submarine rescue ship	ASR	120	59	40
Submarine, diesel	SS	78	34	20
Submarine, nuclear	SS N	110	57	32

6,000 men. Two more ships could have occupied pier berths at the time, but probably would not have caused the maximum population to exceed 6,700, as estimated above.

In the Submarine Base the maximum observed population was 1,400 which corresponds to one full squadron of the two-squadron submarine flotilla. Both squadrons could be berthed in the area at one time, but this situation is also highly unlikely. If it occurred, however, 2,800 persons would be afloat in the Submarine Base.

All fifty-eight mooring buoys were also assumed to be occupied by a single vessel having an average population of 195 men. This would provide another 11,000 persons which, with the other anchorage, would bring the total maximum possible afloat population in San Diego Bay to 38,000.

Commercial Vessels

The two general categories of commercial watercraft using San Diego Bay are cargo vessels and fishing boats. Data on cargo vessels using the port were obtained from the San Diego Unified Port District. Information on the number of ships and the time spent in port was taken from the port logbook. Five months of record were examined.

Many ships were in port less than a full day. For each ship visit the total number of hours was determined and this value was divided by twenty-four to obtain a figure for ship-days/day. An average number of ship-days/day for both the Tenth Avenue Terminal and the "B" Street Pier complex was calculated based on the five-month record. The average population was obtained by multiplying this value by forty-five, the normal complement for cargo vessels. Population figures for commercial fishing activities are discussed in Section VI.

Recreational Watercraft

The number of persons using pleasure craft in San Diego Bay fluctuates with season, weather, day of the week and time of day and cannot be estimated with any degree of reliability. Most of the boats actually in use are in the bay only while traveling from the marina to the harbor entrance. About eighty percent of the pleasure boats are moored at Shelter Island. Travel time from Shelter Island to the harbor entrance is usually less than thirty minutes. An estimate of twenty-five percent use on a maximum-use day was obtained from the marina operators. This amounts to only 500 boats in use at any one time. Assuming a crew of four, and one hour of operating time within the bay for each boat, the maximum population equivalent amounts to eighty-three man-days/day. On occasional weekend days when ocean conditions are adverse as many as thirty boats may be observed cruising in San Diego Bay. The maximum time each of these boats spends on the bay is estimated to be five hours. Assuming four persons per boat, a maximum population equivalent for these conditions would be twenty-five man-days/day.

APPENDIX D. DYE TRACER STUDY

Objectives

The dye tracer study had the following primary objectives:

(1) To determine the fate of a typical waste plume originating in the U. S. Naval Station.

(2) To determine the distribution throughout the bay of a conservative element originating in the Naval Station.

(3) To obtain an estimate of the rate of flushing for San Diego Bay.

(4) To provide data for use in verification of a mathematical model of San Diego Bay.

In addition to meeting the above objectives, the data were provided to the U. S. Army Corps of Engineers for use as an aid in calibrating a physical model of San Diego Bay being constructed in Vicksburg, Mississippi.

Study Organization

The U. S. Naval Station was chosen as the location of the dye release. The ships in this area generate approximately fifty-five percent of the total vessel pollution load entering San Diego Bay and the distribution pattern of wastes from this source was of prime concern. The release point was established at the end of Pier 3 (see Figure D-1), because this pier was undergoing repair during the time of the dye study and would have no ships moored alongside. This reduced the possibility of human interference with the dye dispensing equipment. The end of the pier was chosen so that on the first tidal cycle following initiation of the release the dye plume would be well defined. If a release point nearer the foot of the pier had been selected, the balling effect of the ships and other piers would have made accurate delineation of the plume difficult.

The dye selected for use in the study was Rhodamine WT Solution, a fluorescent dye commonly used in tracer work. The dye is readily soluble in water, has a very low decay rate, and exhibits negligible adsorption to suspended sediments.

The dye was discharged at the water surface on a continuous basis for a two-week period starting at higher-high water slack tide on September 9, 1967. The flow rate was thirty-two milliliters per minute± five percent. A continuous discharge was chosen in preference to single batch discharge so the distribution of dye over a range of tidal conditions could be observed.

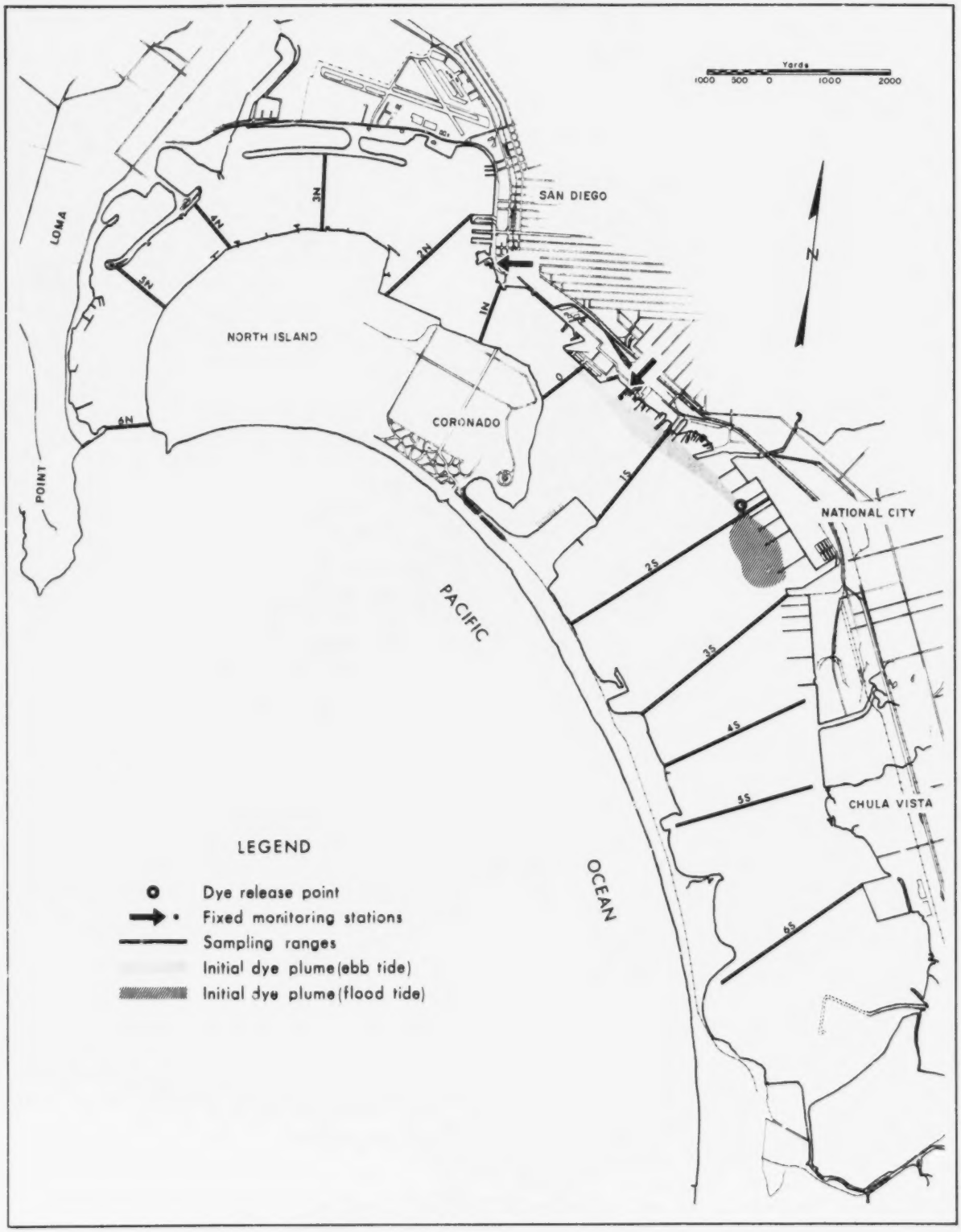
Monitoring of the dye was carried out using five fluorometers installed at fixed shore stations and in boats. Two boats, each equipped with a Turner Model 111* fluorometer and a recorder, were used in conducting most of the monitoring. Thirteen lateral sampling ranges were established from Ballast Point to far south bay. A continuous record of the dye concentration across each range was obtained at each higher-high slack and lower-low slack tide. Vertical profiles were also taken periodically. To provide a backup for the data taken by the boat-mounted instruments, two Turner Model 111 fluorometer with recorders were mounted on shore. These instruments were operated continuously throughout the entire study. Figure D-1 indicates the location of the ranges and shore-mounted instruments.

An American Instrument Company, Inc. fluorometer, Model No. 4-7102*, was kept in the laboratory as a control instrument. Due to differences in the field instruments, all data were converted to a dye concentration as indicated by the laboratory fluorometer. It was also used to evaluate the dye concentration in grab samples taken to verify the correct operation of the field instruments.

Delineation of Waste Plume

One of the main objectives of the study was to determine the extent of the waste plume originating in the Naval Station. Of particular interest was the possible incursion of fresh wastes from the Naval Station into the industrial zone immediately to the north because bay waters in this area are used in food-handling processes.

*Use of this instrument does not constitute an endorsement of this product by the Federal Water Pollution Control Administration.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4N
5N
2N
1N
6N
1S
2S
3S
4S
5S
6S
LEGEND
Dye release point
Fixed monitoring stations
Sampling ranges
Initial dye plume(ebb tide)
Initial dye plume(flood tide)

Figure D-1

Figure D-1 shows the extent of the plume for the initial ebb and flood tide conditions. The tidal range for the ebb was 5.5 feet, which is greater than the mean range for San Diego Bay. The range for the following flood tide was 2.8 feet. On the ebb the plume remained very narrow and hugged the east side of the channel. This was similar to the pattern observed during preliminary studies with visible dyes. Movement of the dye into the industrial zone was apparent and was further confirmed by the instrument located in that area.

General Distribution

The dye was rapidly distributed throughout the central and southern portion of the bay. Increases above background were noted in far south bay in two to three days. In the areas of the bay near the entrance, no significant buildup occurred until a period of five to six days had elapsed. Since there is no freshwater inflow to the bay, and thus no net seaward flow, this lag period is not considered unusual.

The buildup of dye concentration varied considerably from point to point within the bay. In areas south of the dye release point, the concentration was still increasing fairly rapidly at the time the discharge was stopped. Conversely, at points down bay from the Naval Station, the concentrations had either leveled off or were increasing very slowly. In the areas near the Naval Station and industrial area there was a sharp drop in concentration towards the western shore. This is to be expected considering the location of the waste plume as discussed earlier.

Vertical profiles on both high and low tides show relatively uniform concentrations from top to bottom. This indicates that the bay is well mixed with no significant vertical stratification.

Bay Flushing Rate

Dye concentrations were measured at high and low slack tide at all stations for several days following cessation of the dye flow, then periodically over the next three months to determine a rate of flushing for the bay.

In the bay south of the dye release point dye concentrations continued to increase for one to three days then began to drop taking two to three days in mid-South Bay (2S, 3S and 4S) and ten days at 5S and 6S to return halfway to background fluorescence.

Stations at the dye release point and northward took from one to nine days after dye flow ceased to reach peak concentrations, and two and one-half to eleven and one-half days thereafter to return halfway to background.

The short half-life found at Stations 5N and 6N probably results from the more rapid tidal exchange of fresh sea water whereas the short half-life at Stations 2S, 3S and 4S probably result from wider dispersion in the shallower waters of South Bay during tidal flood and the "funnelling" back through the channel on tidal ebb. The longer half-life found at Stations 5S and 6S are probably the result of "spillover" during flood tide and the lower circulation rates in this area of the bay. The "funneling" of water containing higher dye concentrations may also account for the longer half-life obtained at Stations 1N, 2N and 3N. In general, however, the half-life of all stations at high and low tides averaged approximately 7 days.

All stations with the exception of far South Bay showed a return to background fluorescence in 25 to 30 days.

APPENDIX E. MATHEMATICAL MODEL

The mathematical model utilized for simulating coliform distributions in San Diego Bay is structurally the same model developed for the San Francisco Bay-Delta system by Water Resources Engineers, Inc., of Walnut Creek, California. The development, testing, and use of this model has been described in previous publications (1, 2, 3, 4).

For this application, San Diego Bay was characterized by a two-dimensional network of 112 junctions (nodes) connected by 170 channel elements (links). The entire bay was modeled including the channel one and one-half miles seaward of Ballast Point.

The ability of the model to simulate the hydraulic behavior of San Diego Bay was demonstrated by comparing the tidal stages at points within the bay calculated by the model with those given in the U. S. Coast and Geodetic Survey Tide Tables. For this simulation the tide imposed at the seaward boundary (Point Loma) was representative of a mean annual tidal condition in the bay. Other significant hydraulic inputs included evaporation (78 cfs), a diversion to the salt ponds in the South Bay (2.6 cfs), and a cooling water diversion and return (646 cfs). A Manning's roughness coefficient (n) of 0.018 was assumed for the entire bay. The solution for dynamic equilibrium was obtained using a time step of fifty seconds.

Comparison of model results with the tide table data for two bay locations is presented in Figure E-1, together with the specified tide imposed at Point Loma.

Few existing data were available on the distribution or dispersion of a water quality constitutent through the bay. Some knowledge of dispersion in the bay was gained, however, by monitoring the distribution of Rhodamine WT dye during and following a continuous fifteen-day release from a pier in the Naval Station as described in Appendix D. Histories of the buildup and subsequent decline of dye concentration at various points in the Bay were prepared from these data. This tracer release was then simulated with the mathematical model and a comparison made between the model predictions and the field observations. Figure E-2 indicates the location of the comparison points and Figures E-3 through E-6 show the comparative values. For this simulation the dye was treated as a non-conservative with a loss rate of 3.4 percent per day, similar to that rate determined by a study of the Potomac River estuary (5). Background concentration at Point Loma corresponded to field observations. The prototype data illustrated in these figures indicate significant fluctuation in concentration from one sampling time to the next beyond what would be expected from the long-term change in concentration. This is due in part to the continuously changing hydraulic conditions in the Bay resulting from wind induced currents and changes in tidal conditions. In areas with pronounced gradients, the concentration at any point is strongly influenced by tidal excursions and variation in excursion yields erratic station histories. However, the mathematical model used a recurring mean tidal condition with identical tidal excursion distances for every tidal cycle. Thus, no attempt was made to simulate these day-to-day fluctuations of the prototype but only the mean change in concentration. In addition, the prototype concentrations are representative of only a relatively small volume of water at the sampling point. The model predictions on the other hand represent the mean concentration of the volume of water represented by a network junction, which might typically have a surface area one-half mile square. Other factors perhaps introducing difficulties into the simulation are the uncertainty of the loss or decay rate of the dye in the prototype, the level (and origin) of background concentration, and the question of whether the bay is indeed vertically unstratified.

The results of both hydraulic and quality verification lead to the conclusion that the model is adequate to represent dispersion phenomena in San Diego Bay and permit comparison of various water quality management plans.

The simulations of coliform distributions were based on the mean annual tidal conditions described previously. Distributions were predicted for some thirty combinations of discharge source die-off rates, flow rate and coliform type. The inputs to the model runs are summarized in Table E-1.

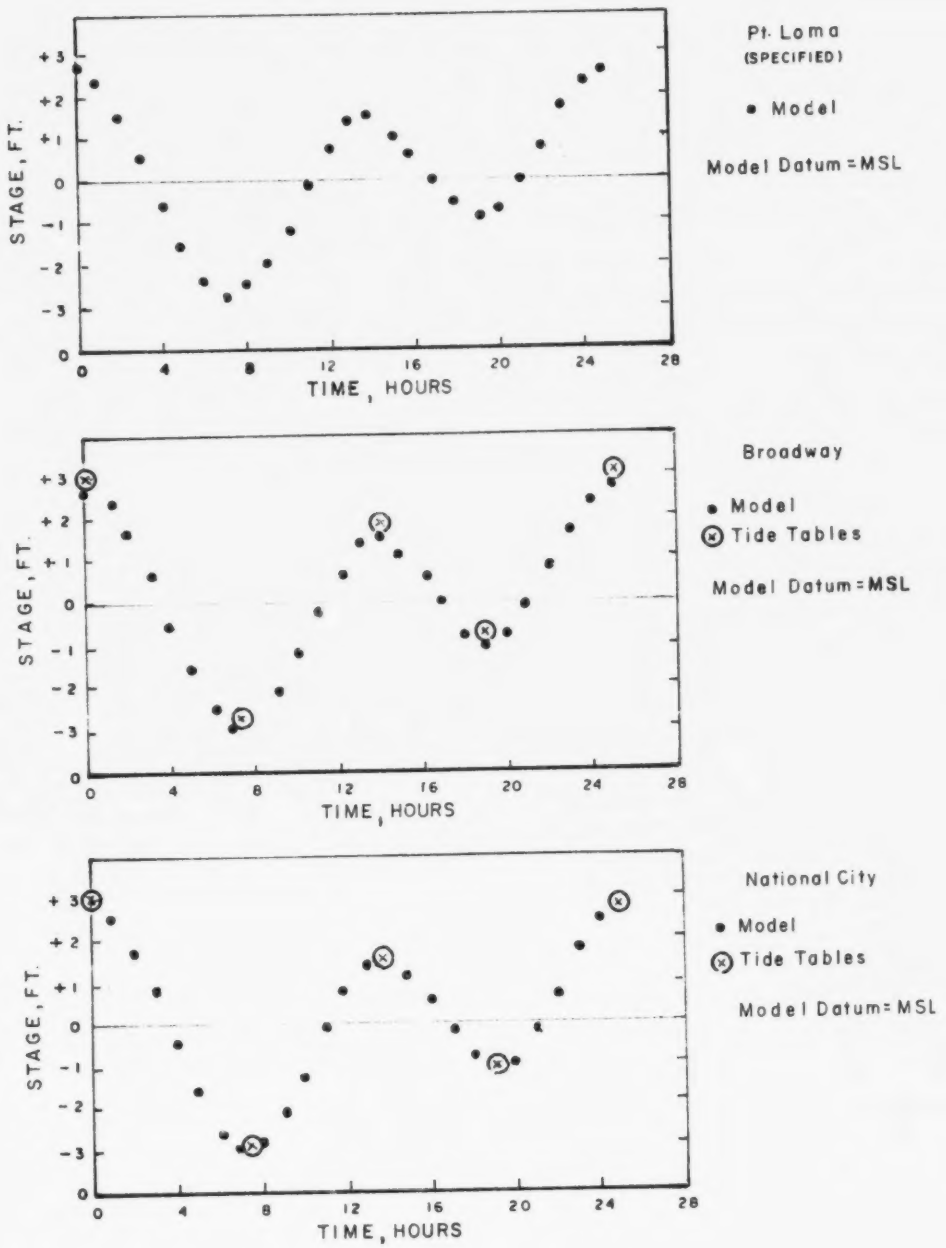
Pt. Loma
(SPECIFIED)
• Model
Model Datum = MSL
STAGE, FT.
TIME, HOURS
Broadway
• Model
⊗ Tide Tables
Model Datum = MSL
STAGE, FT.
TIME, HOURS
National City
• Model
⊗ Tide Tables
Model Datum = MSL
STAGE, FT.
TIME, HOURS

Figure E-1

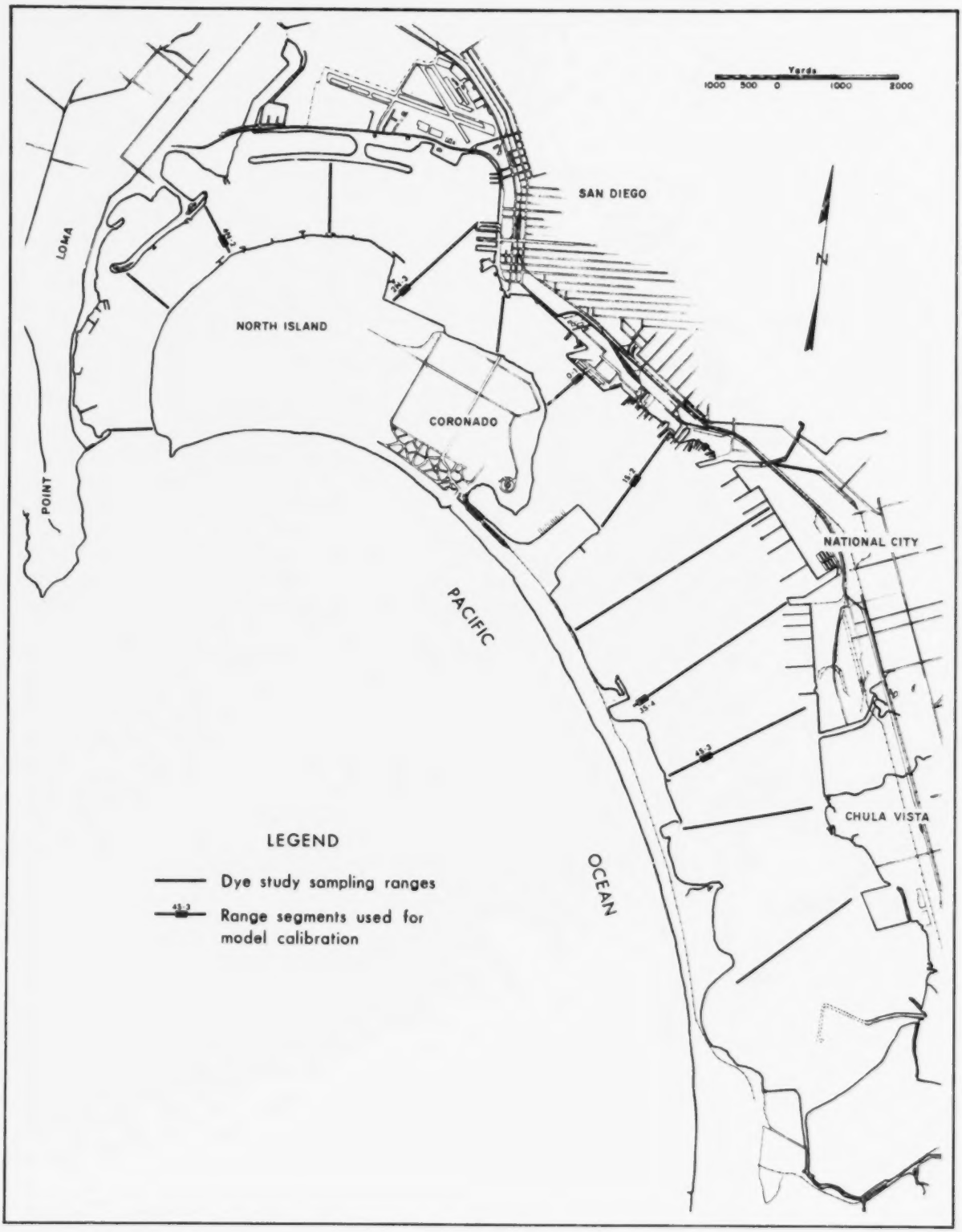
Yards
1000 500 0 1000 2000
N
SAN DIEGO
LOMA
POINT
NORTH ISLAND
CORONADO
NATIONAL CITY
CHULA VISTA
PACIFIC
OCEAN
LEGEND
Dye study sampling ranges
Range segments used for model calibration

Figure E-2

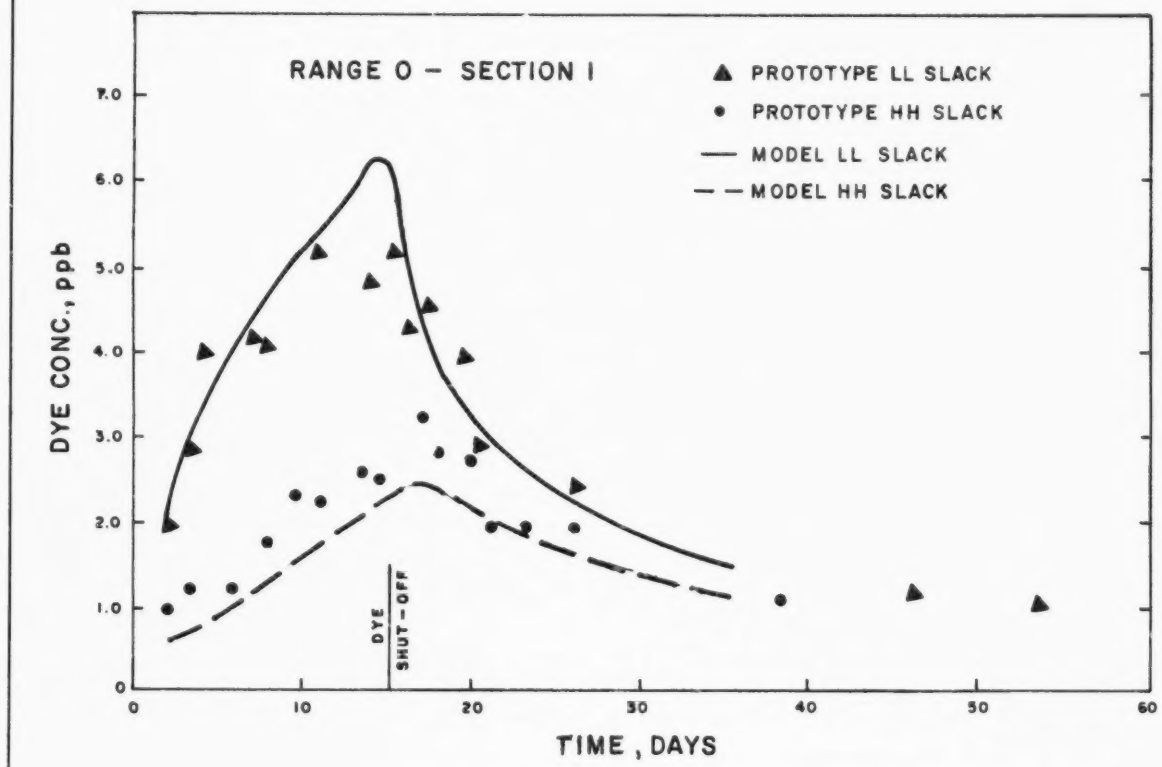
RANGE 0 – SECTION I
PROTOTYPE LL SLACK
PROTOTYPE HH SLACK
MODEL LL SLACK
MODEL HH SLACK
DYE CONC., ppb
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
DYE SHUT-OFF
0
10
20
30
40
50
60
TIME, DAYS

Figure E-3

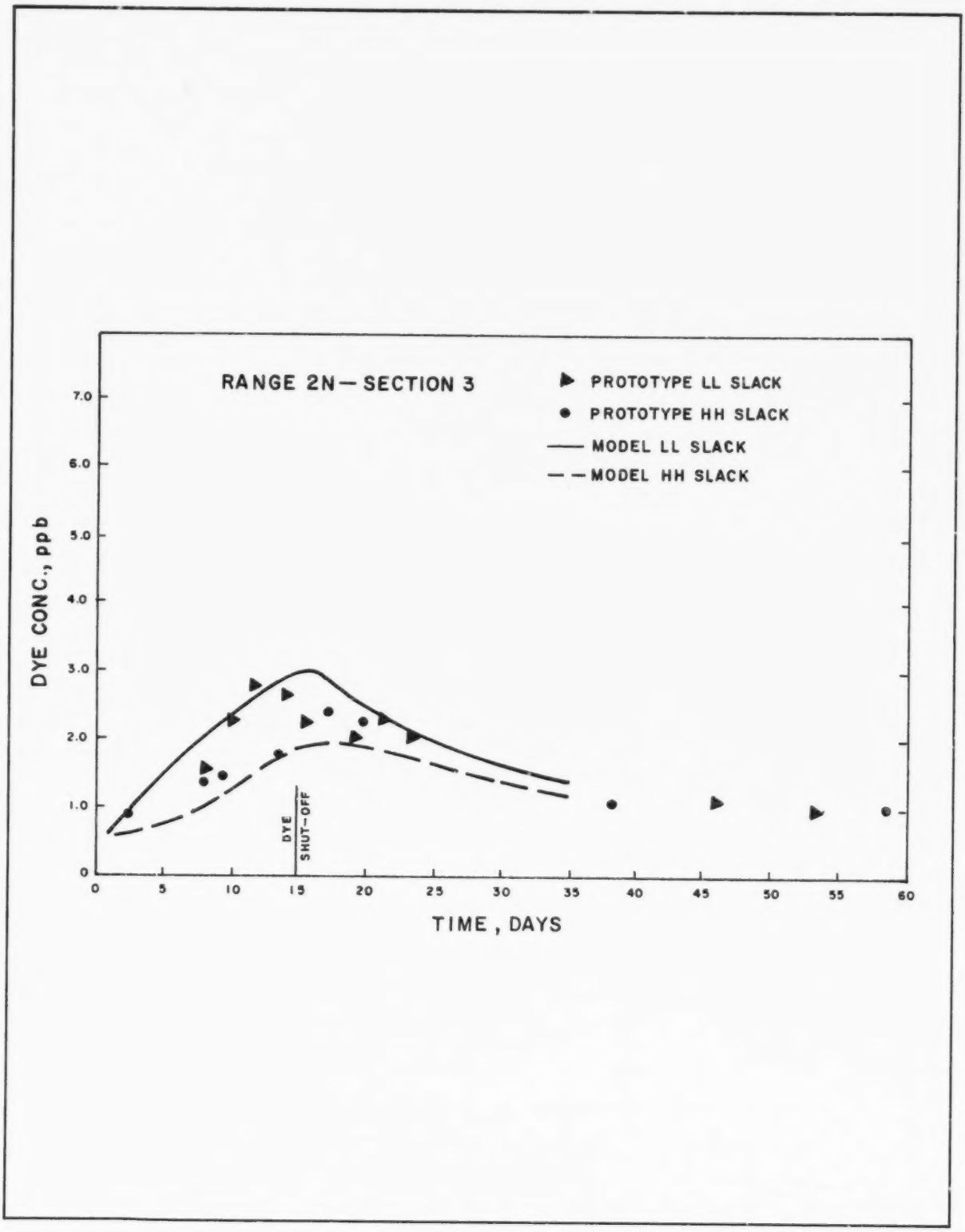
RANGE 2N — SECTION 3
PROTOTYPE LL SLACK
PROTOTYPE HH SLACK
MODEL LL SLACK
MODEL HH SLACK
DYE CONC., ppb
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
DYE SHUT-OFF
0
5
10
15
20
25
30
35
40
45
50
55
60
TIME, DAYS

Figure E-4

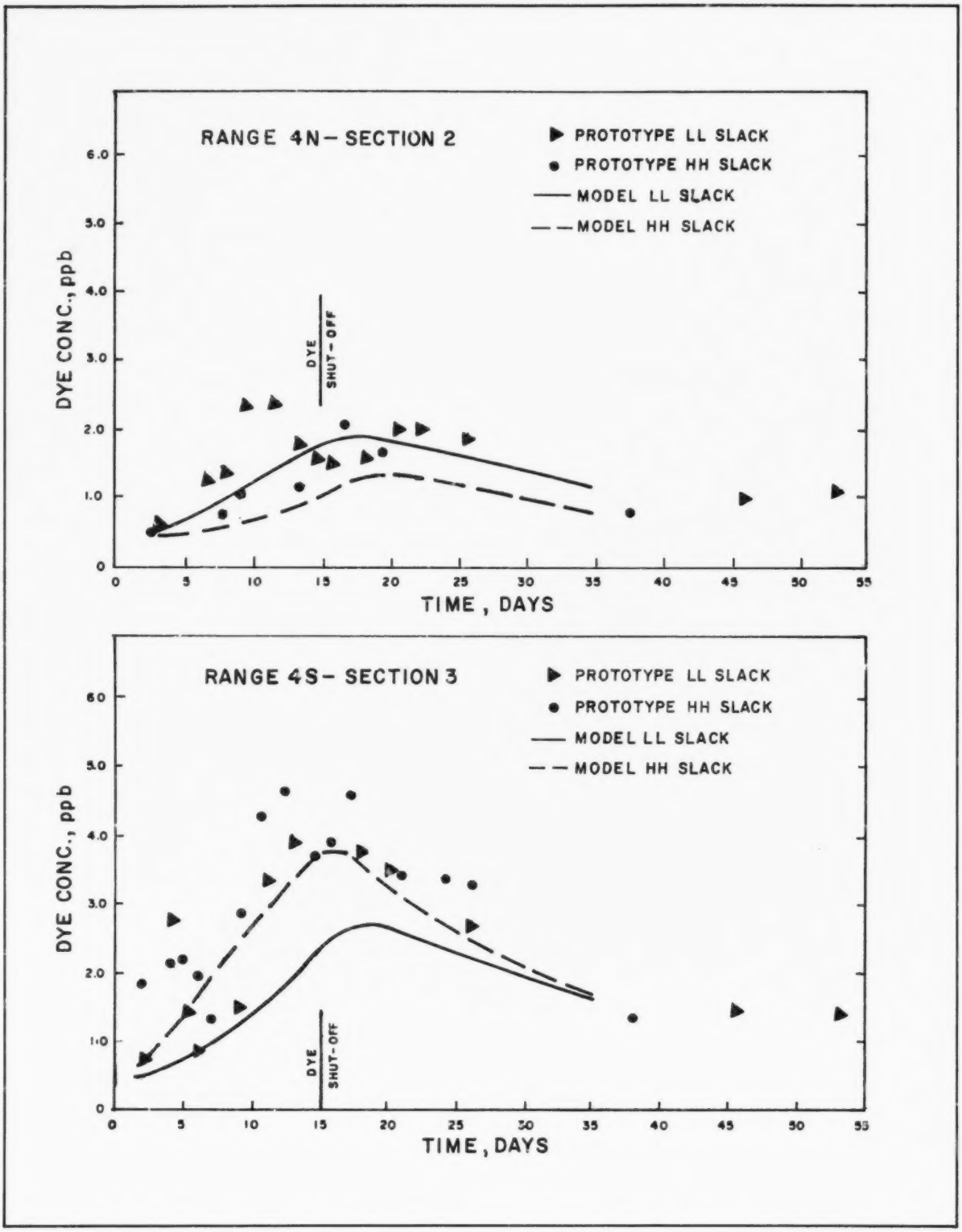
RANGE 4N – SECTION 2
PROTOTYPE LL SLACK
PROTOTYPE HH SLACK
MODEL LL SLACK
MODEL HH SLACK
DYE SHUT-OFF
DYE CONC., ppb
TIME, DAYS
RANGE 4S – SECTION 3
PROTOTYPE LL SLACK
PROTOTYPE HH SLACK
MODEL LL SLACK
MODEL HH SLACK
DYE SHUT-OFF
DYE CONC., ppb
TIME, DAYS

Figure E-5

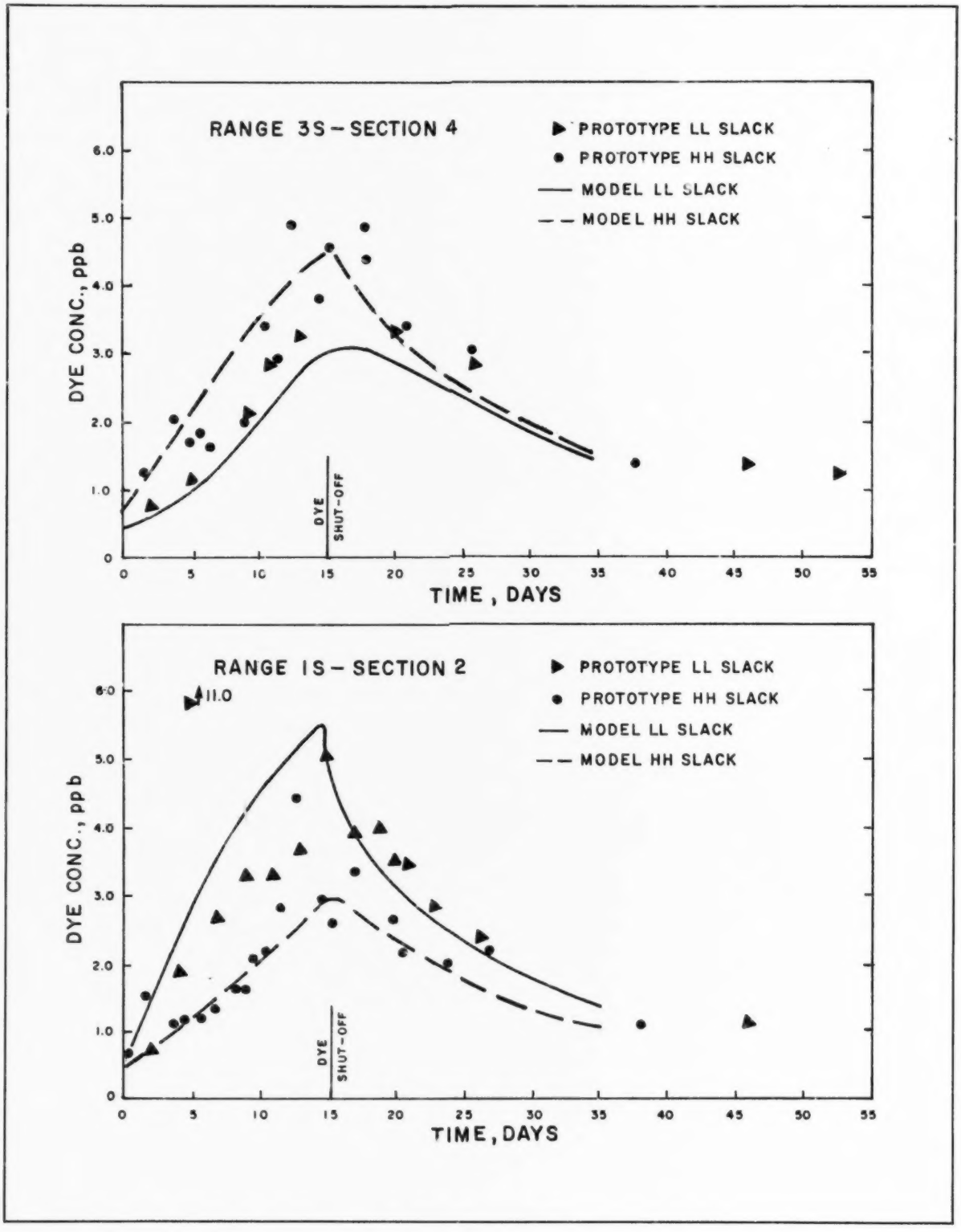
RANGE 3S – SECTION 4
PROTOTYPE LL SLACK
PROTOTYPE HH SLACK
MODEL LL SLACK
MODEL HH SLACK
DYE CONC., ppb
DYE SHUT-OFF
TIME, DAYS
RANGE 1S – SECTION 2
11.0
PROTOTYPE LL SLACK
PROTOTYPE HH SLACK
MODEL LL SLACK
MODEL HH SLACK
DYE CONC., ppb
DYE SHUT-OFF
TIME, DAYS

Figure E-6

Table E-1

SUMMARY OF MODEL INPUTS

SOURCE	DISCHARGE, cfs					Concentrations Coliform/100 ml	
	Industrial only	Industrial plus all Naval Avg. Q.	All Naval only Avg. Q.	All Naval only Max. Q.	Naval Station only Avg. Q.	Total Coliform	Fecal Coliform
Industrial	2.51	2.51	0	0	0	7×10^6	6×10^5
Naval Station	0	0.41	0.41	0.81	0.41	1.28×10^6	5.75×10^5
Other Naval Sources	0	0.23	0.23	0.61	0	1.28×10^6	5.75×10^5

Steady state concentrations of both total and fecal coliforms were determined for each of the five discharge combinations in Table E-1. Three different coliform die-off rates were considered: eighty percent per day, fifty percent per day and zero percent (conservative). Background coliform concentrations from other sources were not considered.

BIBLIOGRAPHY – APPENDIX E

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